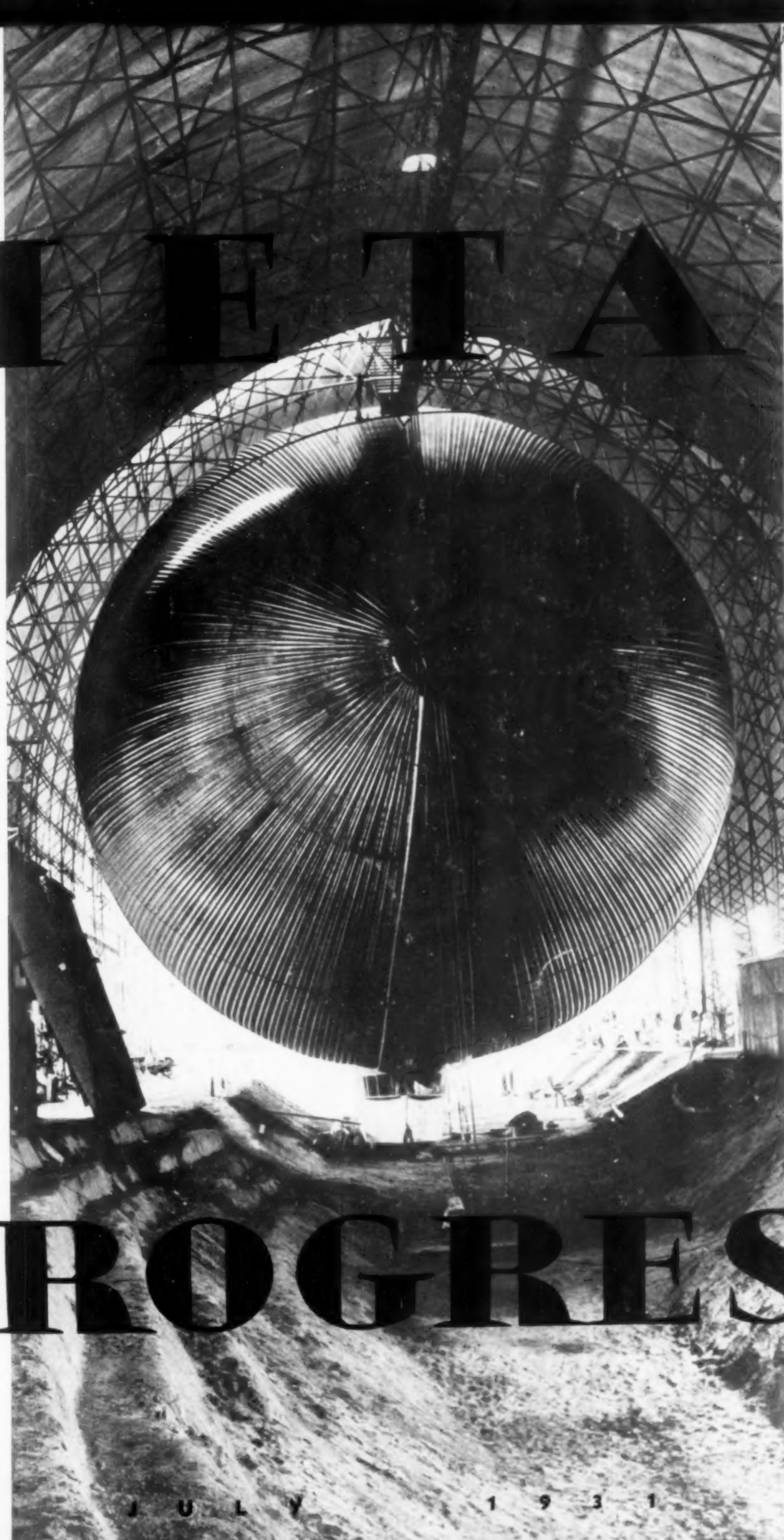
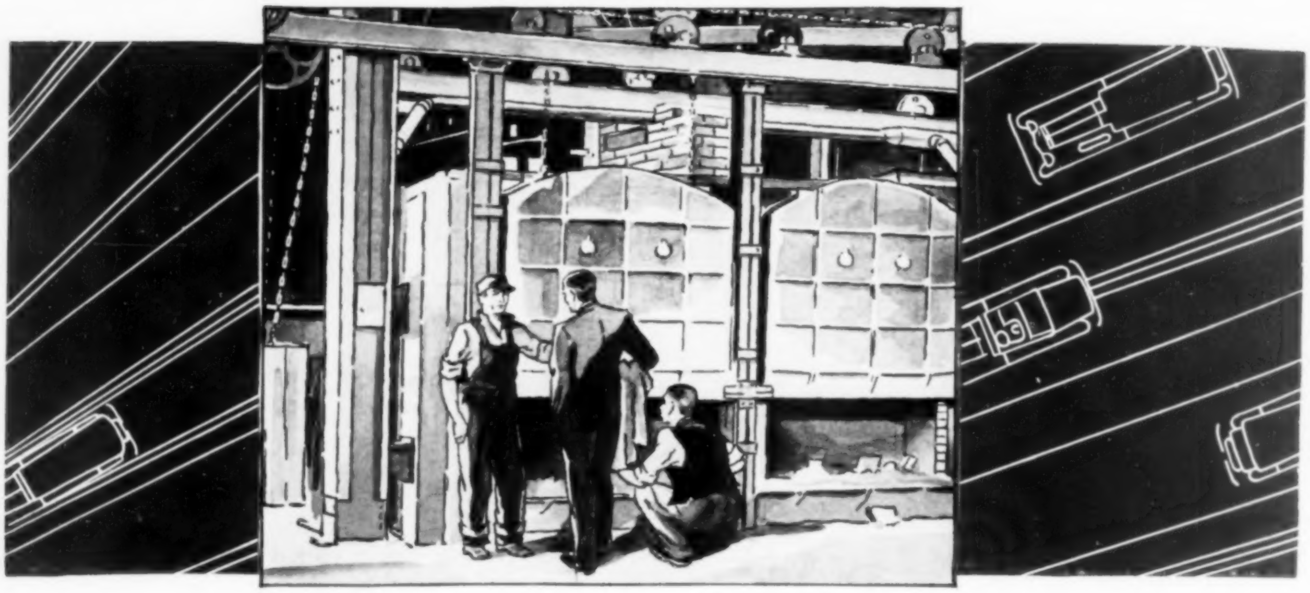
METAL PROGRESS



JULY 1931

The hard spots were in the furnace . . . . . NOT IN THE STEEL



AGAIN came the cry of "hard spots in the steel"... this time from a forge company noted for the quality of its production for the automotive field.

▪ And again Republic Metallurgists—trained tracers of trouble—stepped in.

▪ First, a careful check of the steel...physically...chemically... microscopically. Then, a thorough study of forging operations. Without result...the steel was sound, free from inherent defects and suitable in analysis and physical properties...forging practice was perfect.

▪ In an oil-fired heating furnace, Republic Metallurgists found the cause of the trouble...poorly placed burners...imperfect combustion...unconsumed carbon in the oil forming a small coke residue and falling on the forgings, creating a carburizing effect. The furnace was redesigned, the burners improved and relocated—and the hard spots became one of yesterday's troubles. This incident of several years ago is confirmed in recent metallurgical publications. Feel free to call upon Republic's Metallurgical Staff. It's the perplexity of your problem rather than the size of your requirements that interests the men who have solved hundreds of puzzling steel problems.

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AGATHON ALLOY STEELS

METAL PROGRESS

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Ernest E. Thum, Editor.

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AMERICAN SOCIETY for STEEL TREATING

By John F. Hardecker
Chief Draftsman
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Philadelphia

new

AIRSHIPS

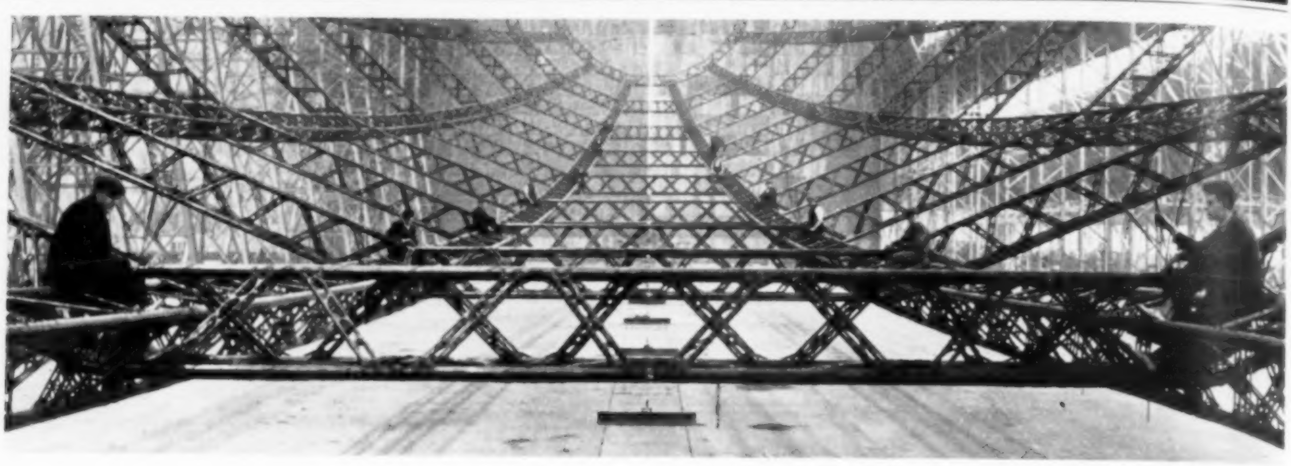
use stronger metals

IN any discussion of the metals used in rigid airships, it is first essential to understand the peculiar background of the development of the design. It has no parallel in modern industry. A product of highly specialized technical skill — a structure of vast magnitude — it can trace its development back over 30 years, yet it musters on roll call less than 200 completely fabricated units. While the modern dirigible has grown from Count Zeppelin's first effort of 400,000 cu. ft. capacity to the 6,500,000 cu.ft. U.S.S. Akron, and has progressed correspondingly in all phases of its engineering refinement, at no time was any "model in production," as we know the term.

The practical consequence of such "custom building" is that at no time has it been feasible to study the application of competitive or alternative materials with that profitable intensity that is only possible under mass production. There is one saving factor in the situation: In a structure of such vast size as the modern dirigible, there are a great many duplicate parts. Therefore, despite the fundamental differences in principles of design and load distribution traceable throughout the evolution of the dirigible (most marked in the contemporary examples), a commendable investigation of the problems of economical utilization and application of materials has been undertaken for each type and design of airship.

Despite the handicaps just hinted, the dirigible has almost invariably pioneered the development of new alloys and fabrication processes. Particularly in the field of light alloys this pioneering influence was felt.

Unlike its heavier-than-air contemporary, the lighter-than-air ship utilized metal in its main structure from its very beginning, while the complete displacement of wood by metal in an airplane is a comparatively recent development. Count Zeppelin's first ship, flown in 1900, had an aluminum and wire framework. In later ships, larger in size, the internal structure was refined — a development greatly influenced by the introduction of duralumin in 1910. This alloy, which has persisted to the present day as the predominating structural material, largely reduced the structural weight and correspondingly increased the useful carrying capacity. While there were occasional and spasmodic attempts to use wood, particularly in the small



Skeleton of R-100 Possesses Many Innovations. Booms are spiral riveted duralumin pipe; diagonal members are pressed from duralumin sheet. All main members end in an easily detachable fitting which fixes them to adjoining parts

German "Bodensee" or "Nordstern" types (and by the British during the War when duralumin was unavailable), these efforts were soon abandoned in favor of metal.

The history of the improvement of duralumin is really the story of metal progress in airship construction. The U.S.S. Shenandoah (American built) and the U.S.S. Los Angeles (German built) were both fabricated essentially of duralumin. Of course, it must be kept in mind that these various ships use alloy steel for internal tension bracing. The world-cruising Graf Zeppelin (the culmination of German Zeppelin development) uses an improved type of duralumin, 20% stronger than that put into the Los Angeles.

British Now Have Largest Ship

The British dirigible, R-100, of 5,000,000 cu.ft. capacity, is the largest airship in existence today. R-100 embodies many original departures in design and construction, but the general arrangement of the main framing follows established Zeppelin practice in other details. The designers adhered to established practice by using duralumin throughout and by building the hull of triangular longitudinal girders which carry the main bending and shear stresses, these being kept in shape by relatively light rings. These rings, regular polygons in outer contour, are made rigid by a system of steel wires in the plane of each ring — much the same construction as a bicycle wheel.

Details of the main members of R-100 are, however, decidedly different from any of those previously used. All of them are fitted at each end with easily detachable joints securing them to correspondingly designed joint members. By this means any damaged girder can be removed by merely unlocking its end joints.

The "boom" or compression flange in the girders is also a distinctly new feature. Previously, these booms have been of the conventional Zeppelin type — an open angle section rolled from duralumin strip. Likewise, the three booms comprising a complete triangular girder have been latticed together, each independent lattice strip being riveted to the faces of the angle-section booms. In R-100 the booms are circular tubes about 5 in. diameter, made from duralumin strip, helically wound and riveted through the overlapping edges like a small spiral-riveted pipe. These tubes were produced at a rapid rate by a novel automatic machine, and are both cheaper and more efficient than the angle type of boom.

Three of these tubes, coupled together by

corrugated lattice work, which is presseed to shape and riveted to the booms, form each unit of the main girders and of the frames.

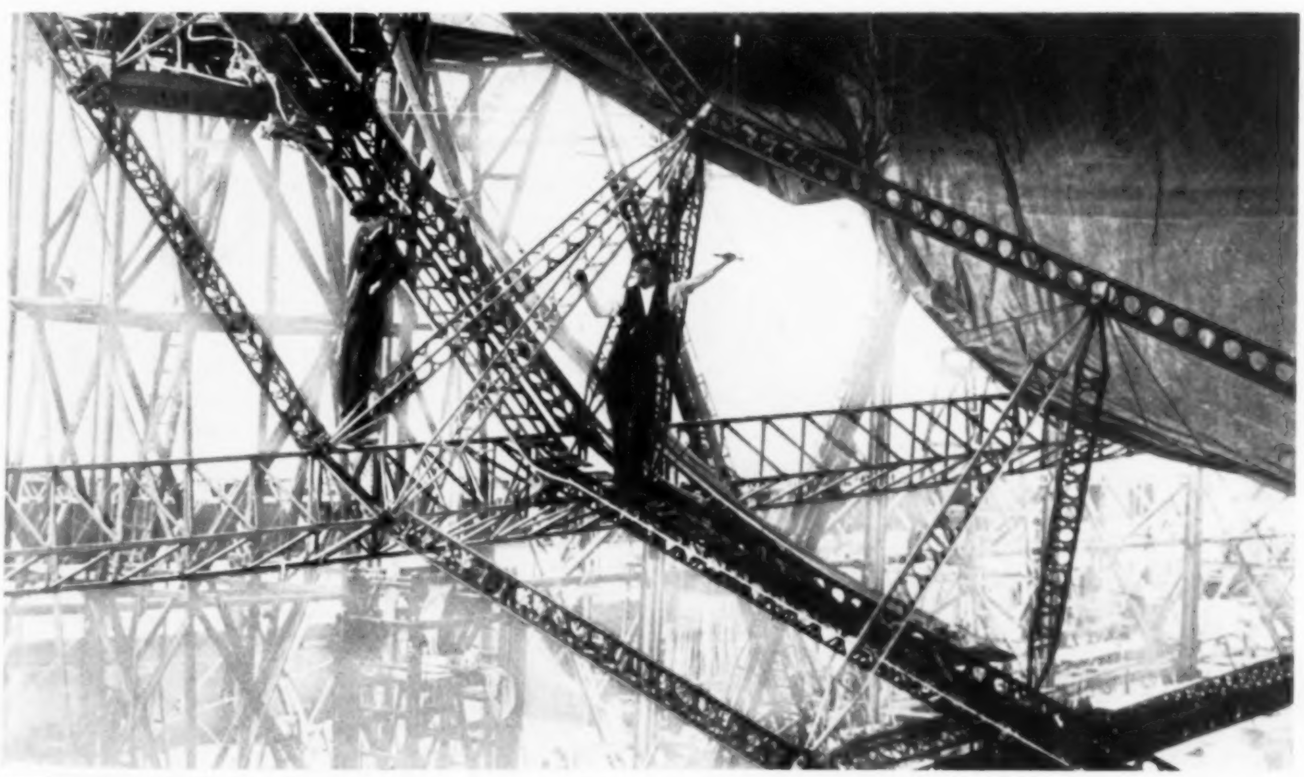
Disaster to R-101 prevented a practical demonstration of one of the most interesting innovations in materials for dirigibles. In the skeleton of this ship was used, for the first time, a considerable quantity of stainless steel. It is impossible to use steel for the skeleton of a small airship, but the "lift" of an airship increases as the cube of its linear dimensions, while the weight increases only as the square of those dimensions. The R-101 had 155 tons lift; a steel framework of a given strength worked out to be lighter than duralumin.

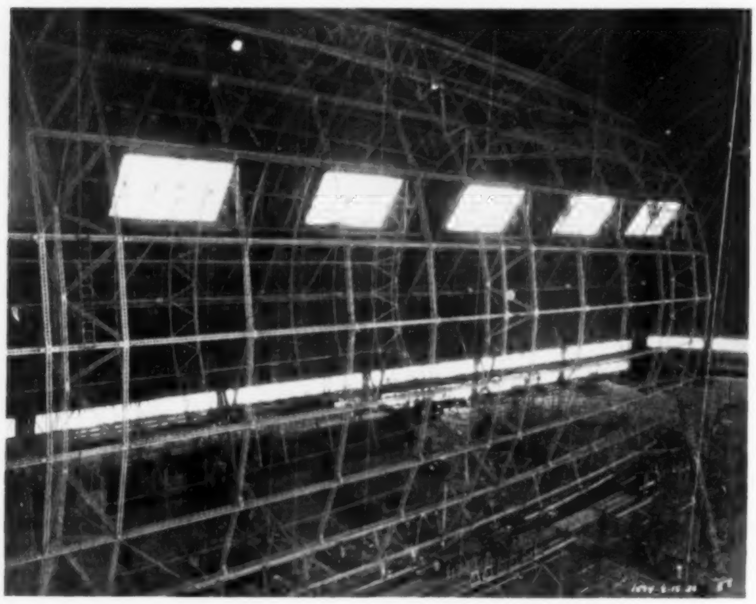
There were about equal amounts of steel and duralumin in the structure of R-101, and this proportion represented the result of years of painstaking research development preceding the actual design and construction. The ultimate failure of R-101 has not been in any way traceable to the use of steel in its construction.

Since the construction of this ship was described in detail in METAL PROGRESS last November it is only necessary to say that main longitudinals (horizontal members in the view) were girders of triangular cross-section; three stainless steel tubular booms were separated by tubular duralumin struts and cross braced with swaged steel wires. An outstanding change in design involved the use of rigid transverse frames; previous practice had been to use frames which were like wheels, with radial brace wires running to the center of the ship.

Stainless steel strip used to form the tubes developed an ultimate strength of 200,000 lb. per sq.in. and had the following composition: Carbon 0.16 to 0.22%, silicon 0.5% (maximum), nickel 1.0% (maximum), and chromium 12.5 to 14.0%. Stainless steel sheets and plates for making the fittings and wiring plates were of an austenitic steel with an ultimate strength of

Horizontal Girders of R-101 Had Booms of Stainless Steel Tube, Struts of Duralumin Tubes and Swaged Steel Wire Cross Bracing. Main members of the rings also had stainless steel booms, bent into bulbous form and webs of duralumin sheet lightened with flanged holes. Nearly all members were pin-connected





Framework of U.S.S. Akron Has Main Rings About 74-Ft. Centers. These are stiff enough so no radial wiring is necessary. Intermediate rings between the three main rings shown are merely to stiffen the longitudinal girders against buckling

130,000 lb. per sq.in., having a composition of carbon 0.14%, silicon 0.36%, nickel 10% and chromium 16%. Drawn steel tubes, hardened and tempered, of the composition employed for axle tubes, with an ultimate approaching 200,000 lb. per sq.in. were used in some places. Steel stampings used for shackles for the bracing wire and similar purposes were all of a high tensile, heat treated steel having a minimum tensile strength of 125,000 lb. per sq.in. Thousands of aluminum-silicon die castings were used, with a minimum ultimate strength of 27,000 lb.

Design of U.S.S. Akron

U.S.S. Akron (ZRS-4), now nearing completion in the plant of the Goodyear-Zeppelin Corp. at Akron, Ohio, will be the world's largest dirigible. (An interesting comparison of characteristics of the U.S.S. Akron with some of her contemporaries is given in the accompanying table). It is built on the "triple layer" principle of Count Zeppelin, having (1) a rigid duralumin framework to withstand the major stresses from the loads carried, buoyant forces, and the dynamic and aerodynamic forces; (2) gas cells within to retain the lifting gas; and (3) a taut fabric outer cover, doped and metallized, waterproofing it, protecting it against the elements, reflecting rather than absorbing heat, and offering a smooth flying surface.

The framework of the Akron is composed mainly of transverse rings connected by longitudinal girders, the latter extending from nose to tail. Over most of the length of the ship, these "rings" are 36-sided polygons, with their corners connected by longitudinal girders. Diagonal wires form a network, bracing the outside panels described by the above structure, while another system of wires and cord nettings transfers the gas cell pressure to the framework.

The view shows two types of rings—main and intermediate. Following the lead of R-101, the main rings are built inherently strong, consisting of two outer annular rings connected in zigzag fashion by cross-girders to an inner annular ring.

The main ring girders are thus triangular in cross-section and are large enough to form corridors for crew members to climb entirely around the ship, facilitating inspection and maintenance. Intermediate rings are of the single girder type and are spaced between the main rings, usually three to a 74-ft. compartment, merely to stiffen the longitudinal girders; the loads are carried back to the main rings.

Throughout most of the length of the ship there are three gangways or corridors, tri-

Principal Characteristics of Modern Airships

	Los Angeles	*Graf-Zeppelin*	*U.S.S. Akron*
Nominal gas volume, cu.ft.	2,470,000	3,700,000	6,500,000
Length overall, ft.	658.3	776	785
Maximum diameter, ft.	90.7	100	132.9
Height overall, ft.	104.4	113	146.5
Gross lift, lb.	153,000	258,000	403,000
Useful lift, lb.	60,000		182,000
Number of engines	5	5	8
Total horsepower	2,000	2,750	4,480
Maximum speed, miles per hour	73.1	80	83.8
Cruising range, land miles	4,000	6,125	10,580

angular in shape. One extends along the top center line of the ship. The other two are placed symmetrically in the lower part, about 45° from the vertical. This arrangement is another departure from Zeppelin practice, which employs a single "cat-walk" corridor along the bottom of the ship from nose to tail.

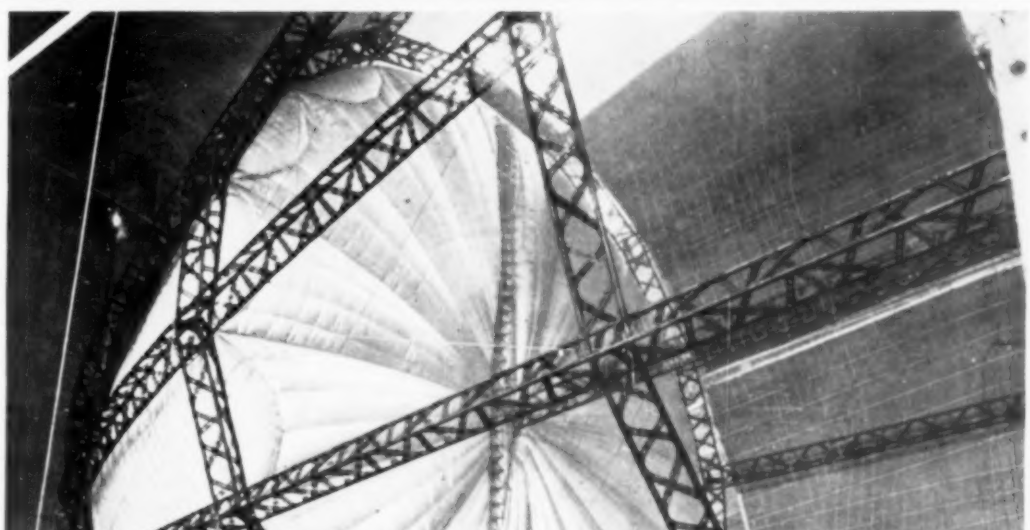
Due to the development of new types of girders on the U.S.S. Akron, it was desirable to obtain a material with high physical properties, especially in compression. The material which offered the most promise considering high yield point and excellent corrosion resistance was the standard duralumin alloy 17S with an added operation after heat treatment which induced the following average physical properties:

Tensile strength	63,000 lb. per sq.in.
Yield point	46,000 lb. per sq.in.
Elongation in 2 in.	13%

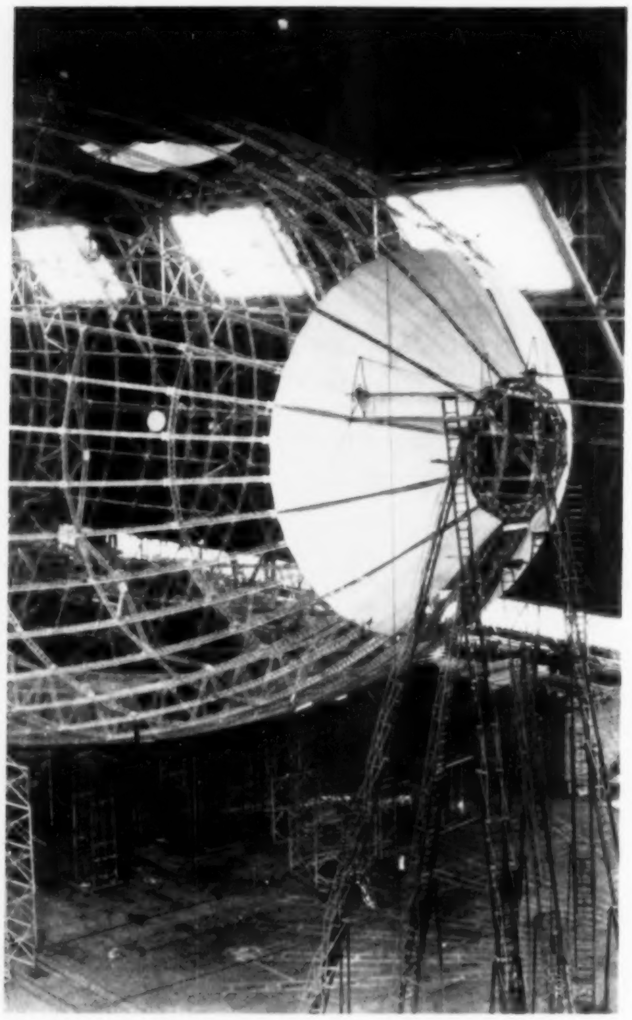
The nominal chemical composition of this alloy is copper 4.0%, manganese 0.5%, magnesium 0.5%, and the balance aluminum.

Rivets used in the structure were formed of 17S alloy. A special type of head was developed by the builders, Goodyear-Zeppelin Corp., which saved considerable weight over the standard button heads.

We now come to the most interesting and significant development — the all-metal dirigible. Roger Bacon had dreamed of this achievement in the thirteenth century, but it was not until the latter part of the nineteenth century that an Austrian named Schwartz actually built in Berlin a rigid airship covered with thin aluminum. This ship was 155 ft. long, had a maximum diameter of 44 ft., and a displacement of about 130,000 cu.ft. In its first flight (1897) the driving belts connecting propellers to the crude engine slipped off their pulleys and the wind-blown craft finally landed in a forest. The task of making a metal ship then passed on to



The "Three Layer" Principle of Count Zeppelin Has Really Five Layers, Three of Them Composite. From outside to inside they are: outer doped fabric (removed in this view), skeleton with shear wiring, gas pressure wiring, cord netting, gas cell lined with gold beaters' skin



U.S.S. Akron Under Construction
Frontispiece is Another View

succeeding generations having available better engines, stronger aluminum alloys, and a higher degree of technical skill.

Encouraged by the availability of these indispensable adjuncts, the Aircraft Development Corp. was organized in 1922 to modernize the rigid airship (already a metal-framed structure since 1900) and make it in fact an all-metal structure like the hull of a seagoing vessel. This seemed an obviously desirable step. The "metal-clad" ZMC-2 airship is the first product. A size of 200,000 cu.ft. was determined to be sufficient to meet the experimental requirements of the Government, and is in no sense to be construed as minimizing its importance as an engineering achievement.

In comparing the metal-clad construction with the conventional fabric construction, it is interesting to note that the surface of the fabric-covered ship, exclusive of framing, really consists of five layers, two of them composite. From outside to inside, there are (a) outer fabric cover with doped coating, (b) shear wiring, (c) gas pressure wiring, (d) cord netting, and (e) gas cell fabric lined with gold beater's skin. These five layers fair the surface, protect it against atmosphere, transmit shear stresses, accommodate varying pressures, and retain the buoyant gas. The single metal surface in the metal-clad ship performs all those functions and performs each of them with less constructional and maintenance cost.

ZMC-2 has a hull 149 ft. 5 in. from bow to stern, and 52 ft. 8 in. maximum diameter. Its covering consists of Alclad alloy sheets, 0.0095 in. thick, sewed together by a special riveting machine developed for the purpose. Alclad, as is well known, is standard duralumin covered with a very thin layer of pure aluminum to prevent corrosion. The maximum size of sheet developed in this thickness was 14 ft. by 18 in. The metal skin contains the lifting gas; consequently seams and rivets are gas-proofed by a bitumastic compound which is applied on the seams and is drawn in by capillary action.

Inside the hull the metal sheathing is held firmly by rivets to a supporting structure built up of transverse duralumin frames and longitudinals. The cross-section of the longitudinals is of the "capital omega" type two inches high; the thickness of the metal from which they are made varies from 0.014 to 0.032 in. Frames are continuous around the ship, while the longitudinals are cut at the frames and are connected by special straddling splices of formed sheets.

Altogether ZMC-2 has five main frames of the heavy built-up type and seven of simple triangular cross-section. In cross-section the frames are 8 in. high on center line and from 8 to 10 in. wide at the base; the channels are made of duralumin 0.025 in. thick, the webs 0.020 in., and the base plate 0.014 in. Each frame is built up of a number of bowed sectors spliced end to end. The main frames are diagonally wired by hard-drawn steel aircraft wire and tie rods. Wires are spliced to eyebolts screwed into Lynite castings as filler blocks.

Without the development and perfection of

an automatic riveting machine, it would have been practically impossible to build the hull of ZMC-2. This machine has successfully driven about 3,500,000 rivets with only one-third of one per cent of defectives. In its operation three strands of aluminum alloy wire are fed like thread into the machine and three rows of rivets are "sewed" simultaneously at staggered spacing. The machine shears off the wire in rivet lengths, these tiny wire lengths are punched through the two sheets of Alclad and revolving cams then form the heads.

With this machine two men are able to accomplish as much as 128 men riveting by hand. It inserts and completes 140 rivets per minute or about 40,000 rivets in an eight-hour shift. The cost per lineal foot of seam is about the same as the cost of sewing, cementing, and taping one foot of fabric seam.

ZMC-2 was built with its axis vertical; the nose was made first, then the next course of sheet, then the next, and so on — the dome-shaped shell was hoisted as it was completed, ring by ring. For its construction, concentric circular tracks were laid on the floor, whose common center was the axis of the hull. A car mounted on these tracks carried the riveting machine around and around. The riveting machine was mounted on the car by means of an arm with a universal movement and balanced by springs so that it could be easily moved to any position, independently of the position of the car, within a limit of about two feet; it pulled itself along the sheet by its own feeding mechanism.

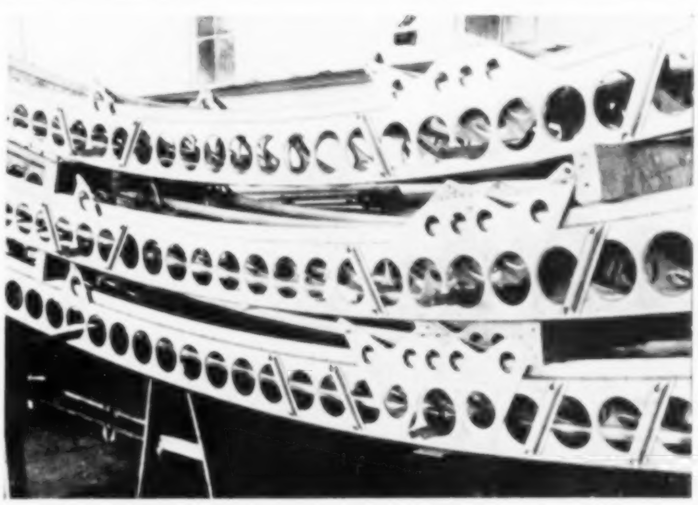
Inside of this structure (the duralumin ribs) was protected against corrosion by anodic treatment and a coat of lanolin. Alclad needed no protective coating other than clear varnish. It is interesting to note that samples removed from the 0.0095-in. hull covering of the ZMC-2 at Lakehurst, after approximately two years' exposure to weather, do not show any deterioration.

In the ZMC-2 the buoyant gas is contained inside the bare metal hull; in the conventional airships, in fabric bags. The latter are flexible enough to adjust themselves automatically to the changing pressures at different altitudes and conditions of flight. A metal hull, on the other hand, is too rigid to provide these adjustments, yet not stiff or strong enough to be safe against collapse from partial vacuum or bursting from over-pressure. (An inside view of the hull under construction is shown on page 68.)

Pressure Inside Metal Hull

The gas pressure must be under control, therefore, by two fabric ballonets filled with air contained inside the ship, one fore, one aft, and surrounded except at attachments by the helium gas inside the hull. These ballonets are connected to external air scoops and blowers.

As the airship ascends into a lighter atmosphere and consequently a lesser external pressure on the metal skin covering, air is exhausted from the ballonets, giving more room inside the hull within which the helium gas can expand, thus lowering its pressure to balance the outside pressure. When descending, which may of necessity need to be comparatively rapid, the reverse process is encountered — air is taken on by the air scoops (and in rapid descent by the blowers in addition). This air expands the bal-



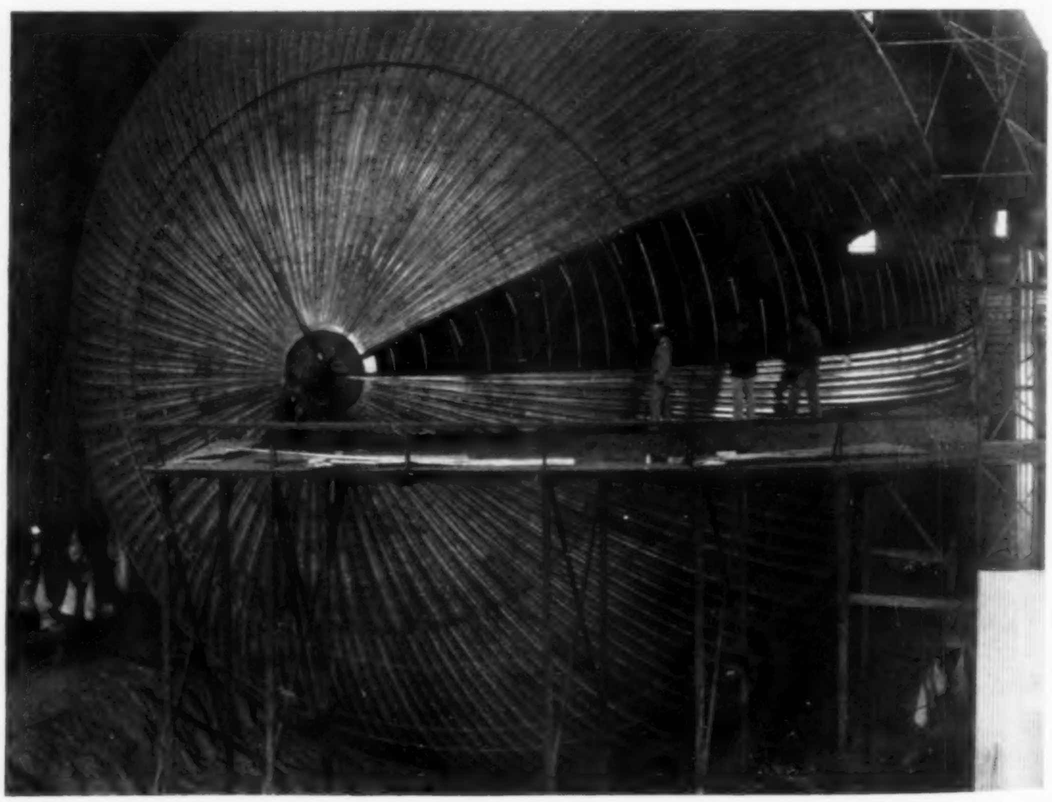
Bowed Sectors for Main Frames, ZMC-2. This ship has a single layer of thin alclad which performs the functions of four of the five layers of the Zeppelin type

lonets, increases the pressure of the surrounding helium gas within the all-enveloping metal cover by reducing the volume occupied by the helium, and thus balances the increasing external pressure.

The Slate airship, "City of Glendale," has one feature of interest to us here — its all-metal hull. It also has other more startling departures from conventional design, such as a blower system of propulsion located in the nose, and a steam power plant. The hull is 212 ft. long by 58.5 ft. at its largest diameter, with a net gas volume of 300,000 cu.ft. Its skin is formed of 0.011-in. duralumin in strips 200 ft. long by 15 in. wide at its largest diameter. This metal cover serves both as a gas-tight container and also as the main structure of the ship. In other words, there is no main framework of longitudinal girders and transverse members, but the strength is built into the cover itself, by forming the hull of corrugated strips mounted longitudinally on circular transverse "ribs" located at intervals along the full length of the hull. The corrugations are also designed to permit expansion and contraction without developing harmful strains. As shown in the view it was also constructed in a unique method — its horizontal axis was fixed to end trunnions and the hull rotated as it was built by workmen on a fixed platform at one side.

In conclusion, it would appear as though the next most logical step in the development of the dirigible would be a larger all-metal ship, say of 2,500,000 cu.ft. This is now being advocated in certain quarters. Such a ship would be of the approximate size of the U.S.S. Los Angeles. It is interesting to note that the official report blames the R-101 disaster to a substantial loss of gas, possibly through chafing of the gas bags against padded projections. If this were a primary cause, a fact which, of course, cannot be definitely established, it would be a distinct argument for the metal-covered dirigible. With the development of the technique of spot welded fabrication of thin sheet stainless steel, and the constant growth in size of dirigibles, it may not be such a wild stretch of the imagination to envisage at some future date the steel-covered dirigible; then truly will it be a modern ship in every respect.

City of Glendale Was Made of Corrugated Duralumin Strip of Sufficient Strength to Eliminate Heavy Rings and Longitudinal Girders



By J. Fletcher Harper
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Milwaukee

GHOSTS

in large steel forgings

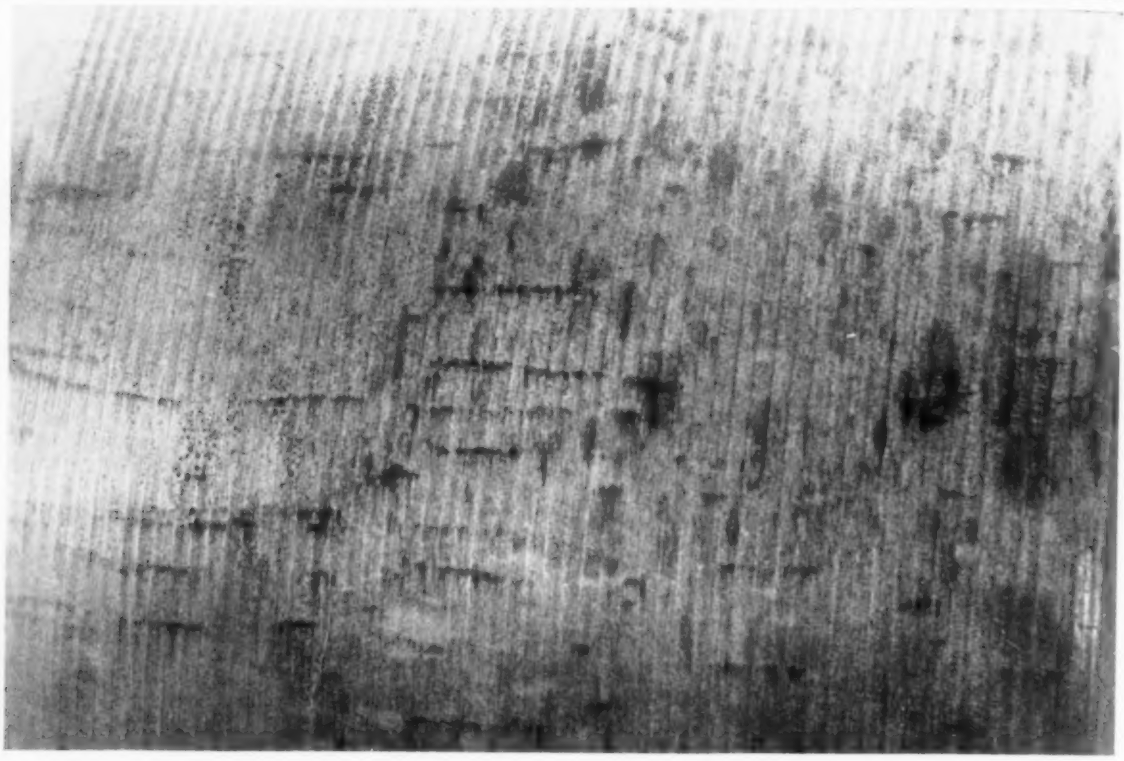
First portion of a paper for the A.S.S.T. Convention, Boston, September 1931

A GHOST or ghost line in a forging is a non-homogeneous streak of metal, in comparison to the main mass; it may or may not contain cracks and non-metallic impurities. Due to its difference in composition from the surrounding metal, more light is reflected from a ghost in a machined surface than from the major portion of that surface. It is the apparent appearance and disappearance with varying angles of light and machining cuts that give rise to the term "ghost" or "ghost line."

They have been noted in large forgings and described by a number of writers, but specific references to the effects of these defects upon the physical properties of the metal are only meager. In this and a succeeding paper some of the physical tests obtained from this class of material will be given and some possible explanations advanced as to the formation of ghost lines.

Examination of forgings during the last 15 years suggests that there are three types of ghost lines, which probably are formed in different manners. These are called, for the purposes of identification, "slow solidification ghosts," "ingot corner ghosts," and "crystallization juncture ghosts." This article will give some of the observations we have made on the first two classes. It is to be regretted that exactly comparable tests were not taken on all the forgings, but the examples given cover a fairly long period of years and various types of forgings; the only tests made were those which, at the time, governed the use or rejection of the forging under examination after the existence of ghost lines had been ascertained.

No attempt has been made to cover the literature exhaustively. In addition to the citations made in the text, we have found the following to contain stimulating thoughts: An article by Horace C. Knerr, entitled, "Influence of Surface Flaws on the Strength of Metals," published in *Automotive Industries*, Dec. 22, 1921; a contribution to the A.S.S.T., 1930, by H. H. Ashdown, entitled, "Steel Ingots"; and an anonymous article in *The Metallurgist* (Supplement to *The Engineer*), which appeared Aug. 27, 1926, entitled "Ghosts."



Ghost Lines Extended Throughout the Entire Cross-Section and Over the Complete Length of This 24-Ft. Shaft

In large sand-cast ingots the rate of solidification is very slow and the temperature gradient (both from the surface to the interior and from the bottom to top) is not great. This slow speed of solidification causes a coagulation of impurities which segregate at various points throughout the ingot. Upon forging, these globular masses of impurities give rise to ghost lines throughout the whole cross-section of the forging, with the possible exception of the outer thin skin of the ingot. It would appear to us that J. O. Arnold's explanation is correct (given in an article, "Phenomena of Ghosts in Forgings," published in *Iron Trade Review*, Nov. 30, 1916) of a definite solution or compound of segregate which freezes before the main mass of material applies to this type of ghost line, and that this substance is the nucleus for the globular ingot ghosts.

B. E. L. de Maré differs slightly from Arnold in his ideas about the composition of the lines (see his address before American Iron and Steel Institute, May 1, 1920, on "Acid Open-Hearth") and Paul E. McKinney, in *Transactions*, A.S.S.T., for July, 1924, in a discussion of the problems of the heat treater as influenced by the pre-natal history of the material, explains the slow solidification ghosts as being principally due to normal chemical reactions which are completed not in the furnace, but after the metal has reached the mold.

Whatever their origin, they have a characteristic distribution in large forgings. The first view shows part of the surface of a shaft with the above-mentioned type of ghost lines. This shaft was 34 in. diameter, 24 ft. long, and was made from a 56-in. diameter corrugated sand-cast ingot. The ghost lines extended throughout the entire cross-section and over the complete length of this shaft.

Longitudinal tension test bars were taken from this forging; the maximum and minimum properties as shown by eight bars, selected at random, were:

Tensile strength	83,600 to 89,000 lb. per sq.in.
Yield point	44,000 to 46,000 lb. per sq.in.
Elongation	29 to 21%
Reduction of area	49.5 to 30%

Chemical analysis of the material in the lines and that from the unlined metal was as follows:

	Carbon	Phosphorus	Sulphur
Ghost line	0.39	0.018	0.057
Ingot metal	0.38	0.016	0.034

These analytical results show a slight increase in carbon, phosphorus, and sulphur in the ghost line. The difference is probably masked by the fact that the test sample of the ghost line material was undoubtedly contaminated with some of the parent metal.

Examination of these lines under the microscope showed inclusions. The molten steel was undoubtedly unusually dirty, and the solid steel was even dirtier from sand contamination from the mold.

A second shaft 13½ in. diameter, 22 ft. long, also contained these slow solidification ghosts. It was made from a 23 in. diameter sand-cast, octagon, acid ingot. It had ghost lines throughout its section and length. It was a nickel steel of the following chemical composition: Carbon 0.306%, manganese 0.55, phosphorus 0.043, sulphur 0.033, silicon 0.163, copper 0.029, and nickel 3.37%.

Before machining this shaft was heat treated by heating to 1,500° F. and air cooling, followed by a reheat at 1,300° F.

It was possible to secure two longitudinal test bars which contained no ghost lines. They were taken midway of the cross-section center to outside, and they gave the following tensile properties:

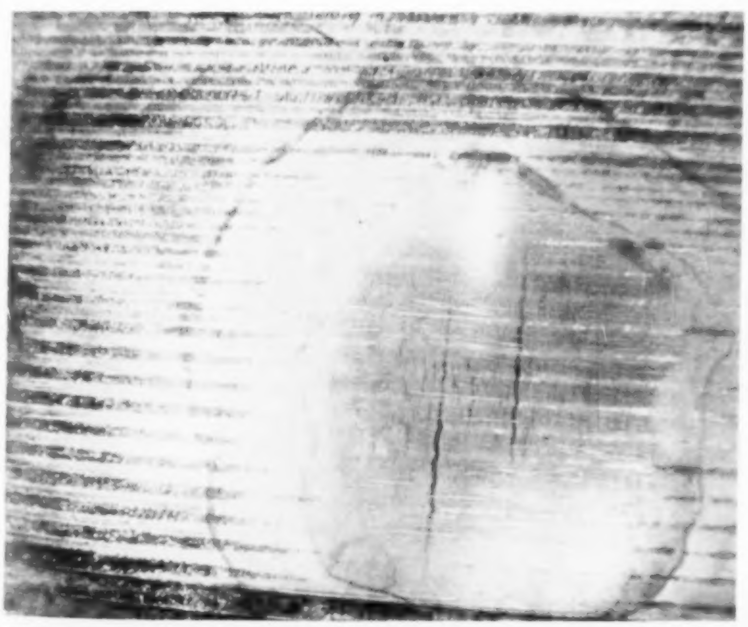
Tensile strength	86,200 and 89,400 lb. per sq.in.
Yield point	51,000 and 53,100 lb. per sq.in.
Elongation	24.5 and 25.5%
Reduction of area	46 and 45 %

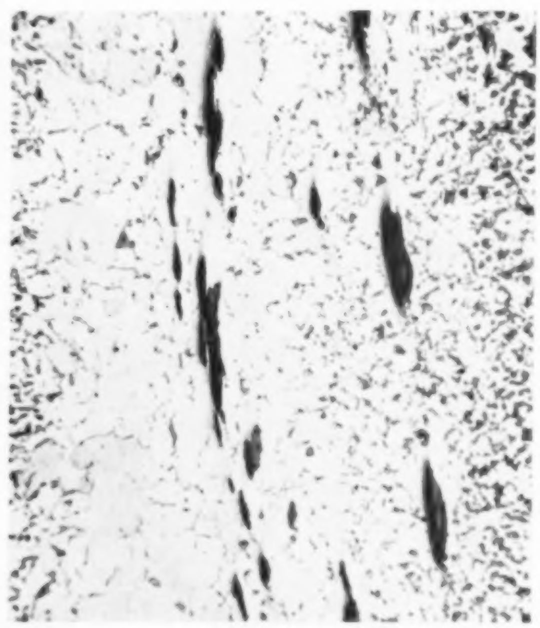
The fracture of the first was silky with a two-thirds cup; the other was gray with ¼ cup.

Properties of Bars With Ghosts

A longitudinal tensile test containing a ghost line showed slightly higher strength and somewhat impaired ductility: Tensile strength 99,500 lb. per sq.in., yield point 58,600 lb. per sq.in., elongation 18.5%, and reduction of area 30%. When examined, the fracture of this longitudinal specimen proved to have a finely crystalline appearance.

Ghosts Like These Occurred at Eight Places, Equally Spaced Around the Circumference of the Shaft. Under the microscope (etched with picric acid and magnified 100 diameters) they were found to be the location of non-metallics and decarburized steel





Corner Ghosts, Rather Less Prominent, From a Twenty-Sided Ingot

Compare these results with those of two *transverse* tensile bars both containing ghost lines, which gave

Tensile strength	89,600 and 78,450 lb. per sq.in.
Yield point	53,250 and 53,900 lb. per sq.in.
Elongation	10 and 5.5%
Reduction in area	14 and 10 %

Fracture was seven-eighths crystalline and three-quarters crystalline, respectively. The ductility, as measured by elongation and reduction in area, was evidently quite deficient.

A second type of ghost lines which appear are those directly traceable to the corners of the ingot mold. F. D. Carney, in a discussion of the effect of sulphur and oxides in ordnance steel, (*Transactions*, A.I.M.E., Vol. 67, p. 337) attributes this type to the entrapment of segregates between the columnar crystals which form from the adjacent sides of the ingot. T. Turner comes to approximately the same conclusion about the cause of ingot corner segregation in a nickel-chromium steel, in an article published in *Engineering*, Nov. 21, 1922.

On the other hand, Leslie Aitchison, in *Chemical and Metallurgical Engineering*, Vol. 23, p. 280 (1920), maps out the "Zones of Weakness in Solidified Ingots." Furthermore, a paper was given before the British Iron and Steel Institute last year by Dr. Soji Maita on "Corner Ghosts in Steel Ingots" in which he attributes them to a condition of stress in the solidification of these large ingots. Due to the weakness of the steel at the temperature near solidification, a fissure is formed in the columnar crystals which either welds, or fills with the mother liquid (which is of less pure metal). This theory implies that a single line in the corner is due to concentrated stress at a sharp corner, while multiple lines show a distribution of stress. It is maintained that corner ghosts can occur in all types of steel in large ingots, but that their occurrence is influenced by chemical composition, impurities, solidification range, crystal form, and thermal conductivity.

Whether corner ghosts are due to entrapment of segregates during solidification or to ruptures shortly after solidification, we have observed what are undoubted corner ghosts more than once in our experience. One instance was in a shaft 40 in. diameter and 14 ft. long. Upon

turning it showed eight areas about equally spaced on the circumference with about two well-marked ghost lines in each area. Tracing the ingot from which this shaft was made, it was found to be a 64-in. octagon fluted ingot, and the eight ghost-containing areas could be directly attributed to the corners of the flutes in the ingot.

A photograph is shown on page 47 of one of these areas slightly etched. It is about ¾ size. A micro at 100 diameters, polished and etched with picric acid, is typical of all of these ghost lines; they show a decided lack of carbon, a high phosphorus content, and large segregates of manganese sulphide.

This ingot was made of acid open-hearth steel, of the following chemical composition: Carbon 0.39%, manganese 0.66, phosphorus 0.014. The sulphur content was 0.046, and silicon was 0.191%.

A series of ghost lines appeared in another forging made from an ingot of vanadium steel which had twenty corrugations. Again the areas bore a direct relation to the convex corrugations. A view at left shows that they were much less pronounced than in the one previously encountered.

This forging, which was 50.5 in. diameter and 142 in. long, was made from a basic open-hearth ingot 84 in. diameter, of the following chemical composition: Carbon 0.50%, manganese 0.82, phosphorus 0.016, sulphur 0.028, silicon 0.160, and vanadium 0.055%.

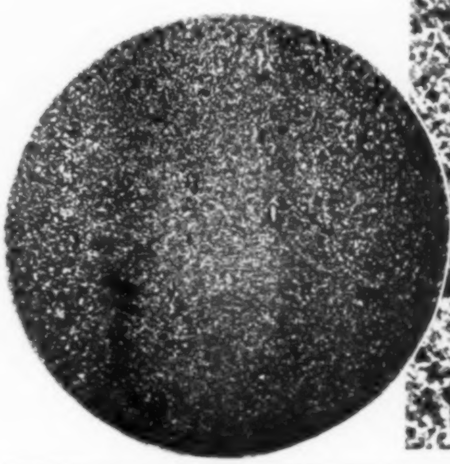
A micro shows the structure of this forging at 100 magnifications, etched with picric acid. It is fairly fine grained and the structure is reasonably uniform.

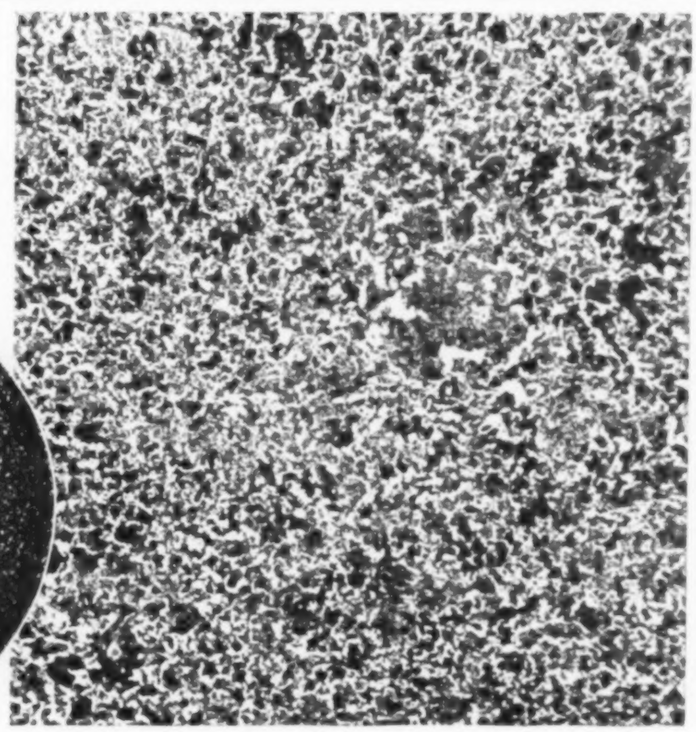
Another, at 36 magnifications, shows a ghost line across the center of the field. Compared with the view of the other forging, inclusions are noticeably absent.

It would appear that Maita's contention as to stress being the major factor in producing corner ghosts would have some confirmation in these examples. The sharp corner of the fluted ingot produced a high local stress and several ghost lines confined to definite regions, while the rounded corner of the corrugated ingot distributed the stress and produced a greater number of ghost lines.

Crystallization structure ghost lines, the third classification mentioned, will be described in some detail in the second portion of this contribution.

Main Mass of Metal (at 100 Diameters) Shows Good Structure. The smaller view, at 36 diameters, is crossed by a ghost line — there is only a slight difference in structural appearance at this magnification





By A. Westgren
Stockholm University

IRON, CARBON, NITROGEN

structural analogies revealed by x-rays

STUDY of the crystal structure of metals received a marked impetus in 1917, when A. W. Hull of the General Electric Co. research laboratory investigated thirteen common metals by means of a new adaptation of X-ray diffraction patterns known as the "powder method." One of them was iron. He found that alpha-iron, the modification stable at ordinary temperatures, has a body-centered cubic lattice with a parameter of 2.86 Ångstrom units.

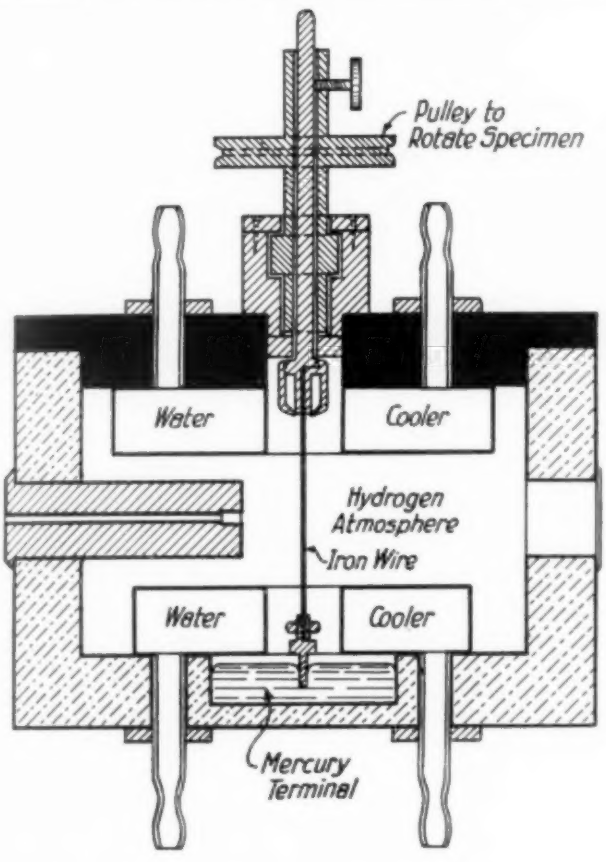
Hull also made an endeavor to determine the atomic grouping of gamma-iron, which is stable within the interval 900 to 1,400° C. He chose a specially coarse-grained iron, which was alloyed with about 3.5% silicon, and studied the X-ray reflections from one of its crystals at ordinary temperature as well as at 1,000° C. No difference in crystal structure at these two temperatures could, however, be discovered. This surprising fact could not be explained; investigation has later shown the cause.

Three or four years later it was discovered by the present writer (and independently by Zay Jeffries and E. C. Bain in America as well as by F. Wever in Germany), that the metal atoms of quenched austenitic steels are arranged in a face-centered cubic lattice. The dimensions of the elementary cube vary with the concentration of the alloy components and the nature of the alloying metal. The iron of austenite being in the gamma-state it was therefore concluded that pure iron in the range 900 to 1,400° C. has a face-centered cubic lattice. The essential difference, therefore, between the allotropic modifications known as alpha-iron and gamma-iron is that the former is body-centered cubic and the latter is face-centered cubic.

This was confirmed by X-ray photograms made by G. Phragmén and the author in 1922 and 1924 of electrolytic iron, which was studied while hot by means of a camera specially constructed for this purpose (shown on page 51). Some of these photograms of pure iron obtained at different temperatures are also reproduced. These patterns show that iron at 800° C. (supposed to be in the beta modification) as well as at 1,450° C. (the delta modification) has the same crystalline structure as at ordinary temperature, that is, body-centered cubic. No phase transformation takes place at the magnetic change point, 768° C., and the so-called beta-iron thus cannot be considered as a special allotropic modification.

Iron, therefore, has only two different

crystalline structures. In its gamma-interval, 900 to 1,400° C., it has a face-centered cubic lattice. (If it could be undercooled to ordinary temperature, it would have a lattice parameter of 3.562 Å, which value Einar Öhman has found last year through extrapolation of a curve showing the change of the lattice dimensions in a series of iron-manganese alloys.) Below 900° C. and from 1,400° C. up to the melting point, iron has a body-centered cubic structure with a parameter at ordinary temperature of 2.8607 Å.



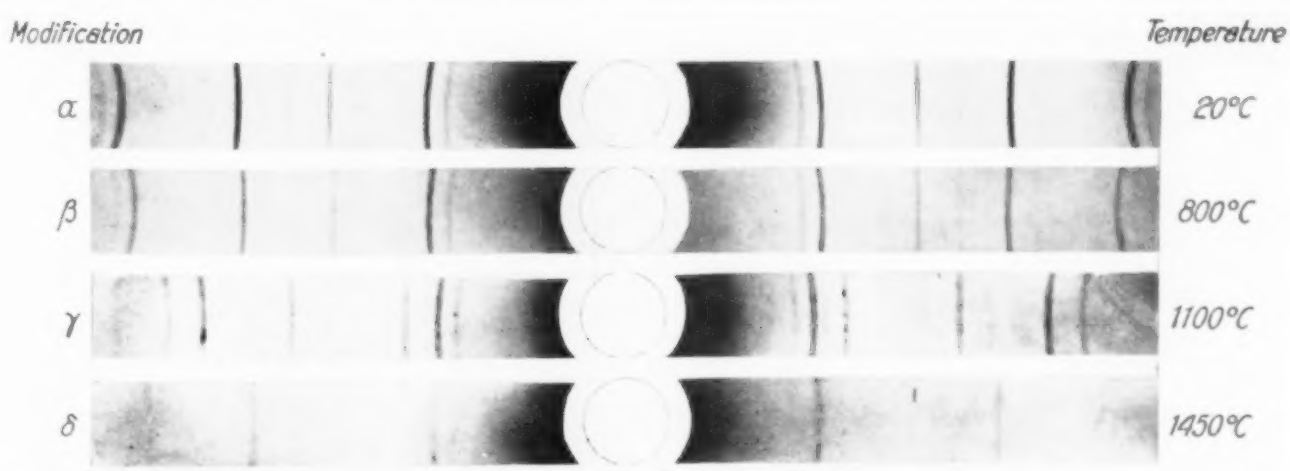
Camera Used to Expose a Rotating Iron Wire (Electrically Heated) to an X-Ray Beam. Photograms so taken show that beta-iron and delta-iron have the same crystal structure as alpha-iron

Cementite Is Very Complex

The only iron-carbon phase existing in simple steels which has the character of a chemical compound is Fe_3C, cementite. What is its essential structure?

Crystals of this carbide, obtained from a specimen of spiegeleisen and thus containing some manganese, were investigated by Phragmén and the present writer about 10 years ago by means of the Laue and the rotation methods. Cementite was found to have complicated orthorhombic lattice, the unit cell of which contains 12 iron and 4 carbon atoms. The edges of the elementary parallelepiped of pure cementite are, according to our latest determinations, 4.517 Å, 5.079Å and 6.730Å. The density derived from these data is 7.67.

A complete discussion regarding the atomic grouping of this substance involves a tremendous amount of calculating, as there are a very great number of different possibilities to consider. Indeed, as pointed out by Prof. McKeehan in his article in METAL PROGRESS last month, the problem can hardly be attacked without making some simplifying assumptions. In this manner Sterling B. Hendricks was able to achieve a solu-



tion of the problem last year, and in a paper in *Zeitschrift für Kristallographie* last year he suggested the atomic grouping shown in the figures.

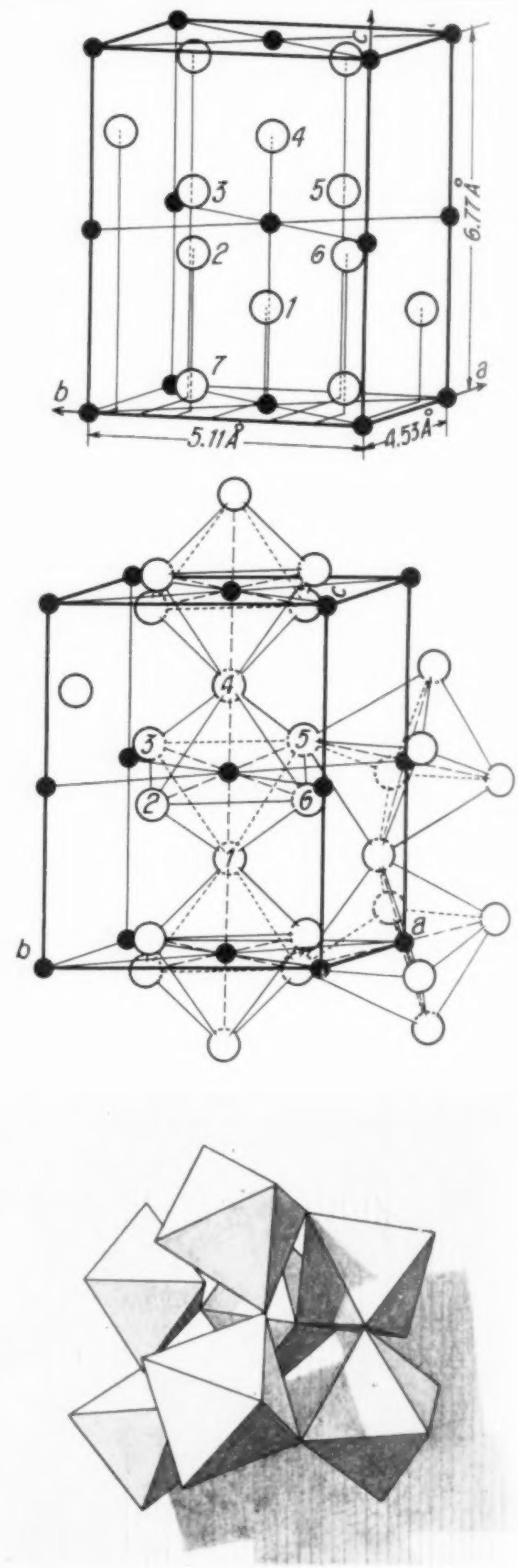
Hendricks' conclusions may be questioned in one respect, namely, the space assigned the carbon atom in this arrangement (a radius of 0.55 Å) is somewhat smaller than the size of the carbon atom derived from a study of the diamond crystal (radius 0.77 Å). But, as will be seen in the sequel, the carbon atom does not occupy more space in the austenite lattice than it has at its disposal in this cementite structure proposed by Hendricks, and his solution of the problem seems altogether quite plausible.

This cannot be said, however, of the structure quite recently proposed by Shigetaka Shimura, and described in a letter from Japan to Metal Progress in January. In his arrangement, some carbon atoms are situated so close to the neighboring iron atoms that the distance center to center of carbon and iron atoms is only 1.22 Å, which is less than the atomic radius (1.26 Å) usually ascribed to iron. Shimura's proposal must, therefore, be considered as highly improbable.

Solutions of Carbon or Nitrogen

As mentioned above, quenched austenitic steels have their metal atoms arranged in a face-centered cubic lattice. A number of photograms of austenite specimens of different compositions, made by the author 10 years ago, indicated that the lattice dimensions grow as the carbon content increases. This was taken as a sign that the carbon atoms in this solid solution are situated in the interstices between the metal atoms, which alone occupy the positions required to build up the face-centered cubic lattice.

A calculation of the density of an austenitic manganese steel confirmed this assumption. Its



Crystal Structure of Cementite, According to Hendricks. The simplest diagram shows the unit of structure containing four molecules of iron carbide; the other indicates how iron atoms (open circles) form octahedra around carbon atoms. An array of octahedra in perspective gives an idea of the interior configuration of cementite structure

CARBIDE AND NITRIDE PHASES OF THE ELEMENT SERIES Sc-Ni

Atomic Radius:	Scandium 1.51 Å	Titanium 1.45 Å	Vanadium 1.33 Å	Chromium 1.27 Å	Manganese 1.29 Å	Iron 1.26 Å	Cobalt 1.25 Å	Nickel 1.24 Å
Carbide Phases	? ScC	? TiC	V_2C VC	Cr_4C Cr_7C_3 Cr_3C_2	Mn_4C Mn_3C ? Mn_7C_3	Fe_3C	Co_3C	Ni_3C
Nitride Phases	? ScN	? TiN	? VN	Cr_2N CrN	Mn_6N Mn_2N Mn_3N_2	Fe_4N Fe_2N	–	–

lattice parameter was determined very exactly by means of a precision camera, and on the basis of the value so obtained the density was calculated on two suppositions, the first that carbon atoms are simply substituted for metal atoms, and the second that austenite is an additive product, that is to say, the carbon atoms are located in interstices in the normal lattice. The values so obtained came out 7.36 and 7.83 respectively. When the density of the steel was experimentally determined in the usual direct way, it was found to be 7.83. Thus, it was definitely proved that austenite is not formed by simple substitution but that it is an additive product. This result, moreover, has been confirmed by F. Wever *(Zeitschrift für Elektrochemie,* 1924) and by R. L. Dowdell *(Transactions* A.S.S.T. 1927).

The lattice parameter of austenite is about 3.60Å. If we assume that the carbon atoms, distributed at random in the lattice, are situated in its largest interstices, we arrive at the value 0.54 Å for the atomic radius of carbon, when the atomic radius of iron is taken as 1.26 Å. This checks the size of the carbon atom as derived from Hendricks' model of the cementite crystal.

A solid solution of this nature is different from that generally found in alloys, which is of the substitution type, but austenite is by no means unique in being an additive product. As Gunnar Hägg has pointed out quite recently *(Zeitschrift für physikalische Chemie,* 1931), the capacity of forming compound phases of this kind is characteristic of all transition elements. When these metals combine with elements having small atoms, such as hydrogen, carbon, and nitrogen, the latter generally enter into the lattice occupied by the metal atoms, which, in most cases, is either close-packed cubic or close-packed hexagonal.

Influence of Size of Atoms

How much hydrogen, carbon, or nitrogen these metals are able to include in their lattice depends mainly upon the relative size of their own and the metalloid atoms with which they combine. As the atomic size of the elements scandium, titanium, vanadium, chromium, manganese, iron, cobalt, and nickel decreases continuously in the direction from scandium to nickel, the capacity of joining with carbon and nitrogen is also lessened. As is shown in the accompanying tabulation, the first three metals are able to take up enough carbon to form the compounds, ScC, TiC, and VC. Their metal atoms are arranged in a face-centered cubic lattice, the interstices of which are all filled up by carbon atoms. (This structure is known as the NaCl type, for it corresponds to the atomic arrangement of common rock salt, one of the first chemical compounds to have its structure definitely determined.)

Of the elements, chromium, manganese, iron, cobalt, and nickel, only the latter four seem to be able to form solid solutions of the austenite type. This is probably connected with the fact that these metals in a pure state — at least in some allotropic modification — each

have their atoms arranged in a close-packed cubic grouping. Chromium is body-centered cubic from ordinary temperatures up to its melting point. All the members of the series from chromium to nickel form, however, carbides of complicated crystal structure, in which the atoms are packed very closely. Also when the metals combine with carbon in this way, their capacity to bind carbon seems to decrease in the direction from chromium towards nickel. Thus, the highest carbide of chromium is Cr_3C_2, that of manganese Mn_7C_3, while iron, cobalt, and nickel form only the compounds Fe_3C, Co_3C, and Ni_3C respectively, the stability of which decreases in the direction from iron toward nickel.

Effect of Nitrogen

Proceed now to consider the combinations of the same metallic elements with nitrogen, which have acquired much industrial interest recently in the process of nitrogen hardening. We find that not only scandium, titanium, and vanadium, but also chromium, form nitride phases of NaCl type. Manganese, the next element in the series, binds as much as about 40 atomic per cent nitrogen.

Iron forms three different phases with nitrogen, the highest being the compound Fe_2N. Another of them contains at ordinary temperature 20 atomic per cent nitrogen and is accordingly called Fe_4N. Its iron atoms are arranged in a face-centered cubic lattice. The iron-nitrogen system has been investigated very thoroughly by Gunnar Hägg, who has found that the homogeneity range of this phase becomes broader at higher temperature. Since gamma-iron also has a marked capacity of dissolving nitrogen, this makes it probable that the homogeneity areas of the solid solution of nitrogen in gamma-iron and the phase Fe_4N flow together at higher temperatures, being actually one and the same phase, and which might thus be considered to be a nitrogen austenite. (Hägg's diagram is shown on this page.)

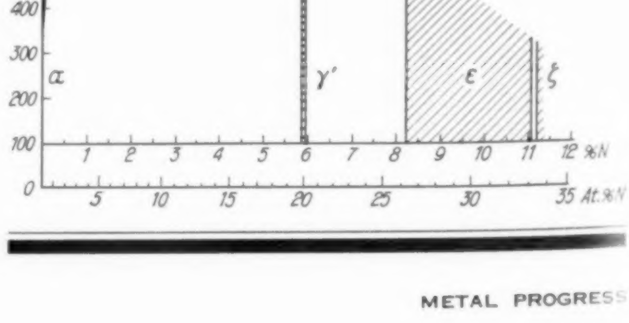
A full account of the regularities of the combinations of the transition elements with carbon and nitrogen cannot be given here. They were described at length in a lecture before the Franklin Institute, Philadelphia, on my recent American trip. The above citations may suffice to show that the solid solution of carbon in gamma-iron is a type of product which is certainly not unique, but has a very great number of analogies. It may, in fact, be conceived as the result of an attempt of iron to form an ideal compound phase FeC, similar to TiC or CrN, which, however, is brought to a stop at a comparatively early stage, because the iron atoms are too small.

Relation to Nitriding Research

Now-a-days many investigations are underway on the nitriding of iron, either in a pure state or alloyed with carbon and metals such as vanadium, chromium, manganese, nickel, tungsten, or molybdenum (which latter all belong to the group of transition elements). In order to understand what happens in this important process, it should be known that there is no essential difference between the reaction of carbon and that of nitrogen with iron and the above-mentioned metallic alloying components.

In conclusion, therefore, it may be said that austenite is a solid solution of iron and carbon, wherein the iron is arranged in a face-centered cubic lattice, and that the carbon atoms are placed at random within the largest interstices between the iron atoms. Nitrogen is absorbed into the lattice in a similar way.

Equilibrium Diagram of Iron-Nitrogen System (According to Gunnar Hägg) Indicates the Existence of a Nitrogen Austenite



By Owen K. Parmiter
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Firth-Sterling Steel Co.

CRUCIBLE

tool steel melting

Prepared at the Request of Subcommittee on Melting, Recommended Practice Committee, A. S. S. T.

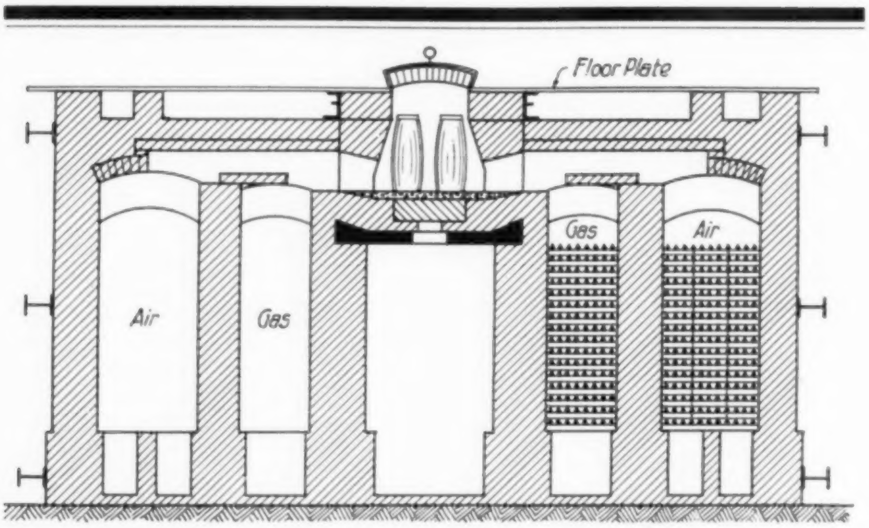
PRODUCTION of iron and steel by a crude modification of the crucible process was practiced thousands of years before the dawn of the present commercial era, but modern tool steel had its beginning with Huntsman in Sheffield, England, in 1740. He revolutionized the original process by melting broken pieces of carburized steel in a crucible, thereby obtaining a more uniform metal. The first tool steel company was established in 1751. Mushet, at the beginning of the last century, substituted refined iron for the blister steel scrap in his crucible mix. Charcoal was added to serve as a carburizer, and the mixture was melted to form "cast steel," as it later became known. From that time on, progress in tool steel was relatively slow until the advent of modern analytical chemistry again revolutionized the production of quality high carbon steel.

In America the few remaining crucible melting furnaces are of the Siemens regenerative type, or some modification of it. The usual furnace has a capacity of 30 pots, each pot accommodating a little less than 100 lb. of steel. The furnace has five openings or holes, which are the melting compartments, and each of these compartments holds six pots.

Regenerative gas and air chambers are arranged on either side of the melting holes. The fuel, which may be either natural or producer gas (usually the latter), is fed into the gas chambers under valve control. The necessary air for combustion is furnished by controlled stack draft. The flame resulting from the combustion of gases in the air and gas chambers is led through ports in the sides of the melting compartments. There are six of these ports or outlets — three on opposite sides of each compartment. Flow of gas is reversed from one side of the furnace to the other every 20 min. Each hole or melting compartment is covered with three steel frames lined with brick, which are removable for charging and pulling the pots.

The bottom of the furnace rests on cast iron bed plates, supported at the sides by the foundation wall of the gas chamber. They are protected from the heat by heavy tile brick. Over these bricks, coke dust is scattered to a depth of about 12 in., which serves as a cushion for the pots, and is of assistance in maintaining an even temperature.

A crucible furnace makes six heats every 24 hr., or 33 heats per week. The remainder of the time is spent on repairs and the general conditioning of the gas producers and the furnace proper. The average recovery of steel ingots



Cross Section of a Crucible Melting Furnace Showing Melting Hole on Top with Regenerative Chambers at Side

from a 30-pot furnace is about 2,800 lb. per heat.

Pots are made from a mixture of natural flake graphite, ball clay and silica sand, which is thoroughly mixed, ground and spun to shape.

An average of about three hours is required to melt a crucible charge of ordinary carbon steel, during which time the crucible cover has fluxed sufficiently to seal the pot and its contents. After a period of "dead melting," and when the temperature is proper, the heat is ready to be pulled. One furnace cover is removed, exposing only two pots at a time. The pots are lifted out by hand tongs and passed to the "teemer," who pours their contents into an ingot mold or a ladle. The total weight of the crucible and its contents, together with the tongs, is about 150 lb., and in pulling the pot, the operator is obliged to straddle the furnace opening and make a lift of almost three feet directly upwards.

The crucible method is not one of refining; impurities such as sulphur and phosphorus cannot be removed. In selecting raw materials, this fact must be given careful consideration. A typical crucible mix for 1.0% carbon steel will consist approximately of the following:

Ingredients	Actual Amounts	% by Weight
Puddled bar iron	76 lb.	80.50%
Crucible steel scrap	17 lb.	18.00
Charcoal (75% fixed carbon)	20 oz.	1.25
Ferromanganese (80% Mn.)	4 oz.	0.25
	$94\frac{1}{2}$ lb.	100.00%

Eight ounces of river sand per pot is used to form the necessary flux.

All of these materials are accurately weighed and checked separately for each individual pot.

Practically all crucible mixes are based on puddled or charcoal iron. Not only must the iron be of the best composition obtainable, but it should be reasonably free from slag inclusions. Removal of all surface oxidation by tumbling or sand-blasting is a valuable preliminary. Steel scrap recharged should be clean. Charcoal should be of the hardwood variety, in pea-size pieces, with a high fixed carbon content; it should be screened to remove all dust. The ferromanganese should be of the low-carbon variety, in clean lumps, uniformly small.

Charcoal (in bags), fluxing sand and ferromanganese are placed on the bottom of the pot, followed by all of the iron. Steel scrap, having the lowest melting point, is added near the top of the pot. Mechanical shaking devices are used to pack the charge thoroughly so that the covers will fit tightly on the crucibles. This is an important and necessary detail.

In the routine of crucible melting, as soon as the hot pots are emptied of their molten steel, they are refilled with a new, cold charge, and again set in the furnace. They are brought up to the melting hole on small specially designed buggies. Usually, a pot can be refilled five times, thus making the total life of the pot about six heats.

The melt down should be accomplished rather quickly in a hot furnace. Gas and air should be adjusted so as to give a neutral or slightly reducing flame, and the furnace should be operated so that the steel is melted and clear in from $2\frac{3}{4}$ to 3 hr. After this, about one hour is spent in killing or dead melting the steel. During this important operation, the furnace should be run considerably on the hot side for the first 30 min., tapering off to the cool side of the proper range for the remainder of the firing

period. This operation serves to deoxidize and degasify the molten metal, at the same time to permit any inclusions of non-metallic particles to come to the top and be absorbed by the slag.

During this period, the molten steel also absorbs both carbon and silicon from the pot, the amount depending upon time and temperature, also the make of the pot. The silica in the pot is reduced and absorbed as silicon under conditions very favorable to the complete deoxidation of the steel. Thorough training and long experience on the part of the melter are vital factors in determining when the steel has had sufficient "fire" to rid it of non-metallic particles and dissolved gases. Too little fire is indicated by a prolonged burst of sparks upon removal of the crucible cap. Too much fire produces an ingot with a leady structure, and the resulting bar fracture appears dry and dull. Excessively high temperatures are also accompanied by a display of sparks, but the experienced melter can readily determine whether the wildness is due to insufficient deoxidization or a superheated condition of the steel.

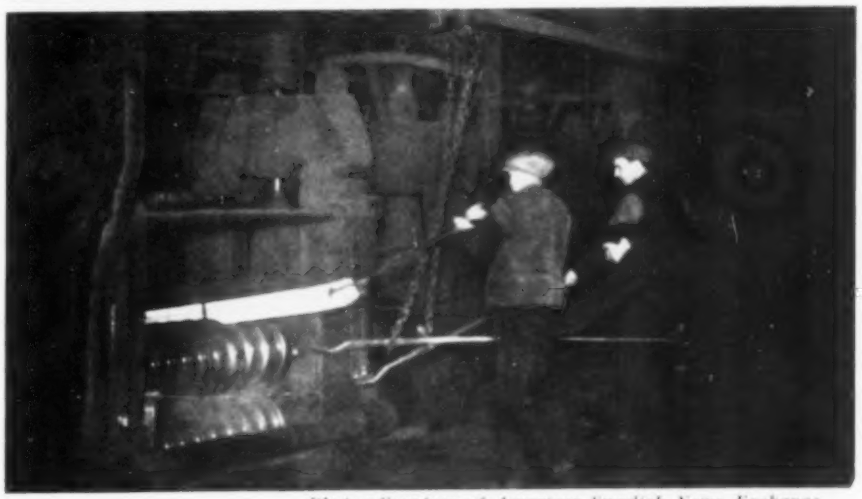
The term "refining" as applied to the melting of ordinary steel usually implies the removal of undesirable impurities such as sulphur and phosphorus by oxidation or reduction in the presence of a basic flux. In crucible melting, such a process of refining is impossible because, while the pot is reducing in action, it is also of a siliceous or acid nature, which necessitates the use of an acid slag of glass or sand. Oxides and dissolved gases are removed by the reducing action of the pot. Silicon is absorbed in amounts as required and under ideal conditions to insure complete deoxidation. Carbon in the proper form is absorbed slowly from the charcoal by the iron to produce stable carbides of a nature highly desirable for complete solution and uniform distribution in the finished steel.

In crucible melting, all ingredients should be added to the original charge. Once the pot cover becomes sealed by the fluxing action of the container, it is seldom removed until the steel is ready to teem or pour. Exclusion of atmospheric gases during melting and during the subsequent firing period is one of the reasons for the high quality of crucible steel. In rare cases, additions are made to the pot of molten steel in the furnace through a length of pipe which serves as a funnel, but steels requiring such practice should not be melted in a crucible furnace.

Adjustments in Mix Are Rare

Once a mix is proven, adjustments are seldom necessary. Occasionally, the carbon content may vary slightly from the desired amount, but this can be corrected by adjusting the amount of charcoal for the following heat. There is always a carbon pick-up (due to the fact that the pot itself contains more than 50% by weight of flake graphite) and this varies, depending upon the number of heats that have been made in the pot, but it can be regulated by proportionately increasing the amount of charcoal in the later heats. Time and temperature during the killing period also affect the carbon pick-up, and this will vary considerably unless operating conditions are held uniform by the melter. Carbon uniformity, heat to heat, is usually a good gage of the experience and ability of the melter.

Proper temperature for teeming depends largely upon the skill and experience of the



Photos Courtesy of American-Swedish News Exchange

melter. Intelligent application of the various valves and controls at his disposal, in combination with an uncanny eye for temperatures, usually results in the steel being poured at a temperature nearer the ideal than by any other method of melting. Excessively high temperatures, by which the molten steel is superheated far beyond what is best suited for quality, are impossible in the crucible process, since neither the furnace nor the pots will withstand such abuse. The temperature may be adjusted for either hand teemed ingots, or somewhat higher for ladle practice. In hand teemed work, the speed of pouring is always under the control of the melter. If, in his judgment, the temperature is on the hot side, the steel is teemed slowly; if on the cool side, it is poured faster.

Silicon Is the Deoxidizing Agent

Crucible steel depends for deoxidation upon silicon absorbed from the pot. If the killing time has been sufficient to give to the steel the proper silicon content, and the temperature is correct, then the steel is ready for pouring. Just before this teeming operation, the slag is removed from the molten steel, thus exposing its surface to the atmosphere. Provision for this temporary exposure to oxidizing influences is made by dropping a pill of metallic aluminum into the pot.

Aluminum is not intended to deoxidize the steel, but to prevent oxidation and to keep the steel quiet until it can be teemed. As a matter of fact, the steel should be quiet and thoroughly deoxidized before removal from the furnace. The average weight of the aluminum pill added to each pot is about one-tenth of an ounce. It should never be more than four ounces to the ton. Intelligent use of aluminum in crucible steel is without detrimental effects from the oxide, although this statement is one which is known to arouse some controversy among crucible steel men.

During recent years, the crucible furnace has been supplanted gradually by the electric arc furnace. Very few crucible furnaces remain in the United States today. The latest progressive step is the development of the induction melting furnace, which threatens to displace even the electric arc furnace in the melting of high quality tool steel.

By Charles A. Scharschu
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CHROMIUM IRON ALLOYS

have remarkable properties

LOW carbon chromium steels or "chromium irons" are of more general interest than the higher carbon steels discussed in the May issue of METAL PROGRESS because their properties make them more suitable for fabrication, which permits of much wider application. Low carbon alloys with from 5 to 30% chromium are being used for various purposes. Within this range, various compositions have become more or less standardized.

Alloys containing carbon under 0.12%, chromium from 12 to 16%, and nickel under 0.5% were earliest used, and have become a standard type because of their excellence as an engineering material. They can be air hardened; tempered at different temperatures they give a range of tensile strengths (coupled with such high ductility and impact values) that an ideal material is produced for many purposes. The range of physical properties that can be obtained in a 12% chromium alloy in this classification is shown in the diagram on page 62.

An important application for this type of alloy is for blades for steam turbines. For this service the maximum strength that can be obtained without undue sacrifice of toughness is required. Several thousand tons of this material has been produced with the following physical properties:

Tensile strength	100,000 lb. per sq.in.
True elastic limit	70,000 lb. per sq.in.
Elongation in 2 in.	25%
Reduction of area	70%
Brinell hardness	200 to 225
Izod impact value	80 to 100

As an engineering material, this alloy has an amazing combination of desirable properties. It is a relatively cheap material (as compared with other alloys proposed for this service) and it couples great strength with ductility and resistance to shock. It is air hardening, which eliminates costly heat treatment; in most applications its corrosion factor can be eliminated. It is readily machinable. A most important point is that it retains its strength at temperatures up to 750° F. It would indeed be difficult to find an engineering material with such a wide range of useful properties.

The temperature ranges necessary for the working and heat treating of this alloy are: Forging, 1,700 to 2,000° F.; softening to 180 Brinell, 1,400 to 1,450° F.; annealing to 150 Brinell, 1,550 to 1,600° F.; and hardening to 360 Brinell, 1,800° F.

The chromium irons are very resistant to nitric acid, and for this service large quantities of an alloy with still higher chromium content than the foregoing have been used. Its remarkable corrosion resistance and physical properties, however, have caused its use to be extended to other fields than the manufacture of acids.

16 to 19% Chromium

Its composition is carbon under 0.12%, chromium, 16 to 19%, and nickel under 0.50%. It has the following physical properties:

	Water Quenched From 1,800° F.	Annealed
Tensile strength	159,000	65,000 to 85,000
Yield point	122,000	35,000 to 50,000
Elongation in 2 in.	4%	30 to 40%
Reduction of area		55 to 70%
Brinell hardness	275	150

About the same temperature ranges for forging, softening, and heat treating should be used as for the 12 to 16% chromium alloy. It is more resistant to corrosion than the latter, but as an engineering material it does not have the capacity for hardening. Referring to the equilibrium diagram printed in METAL PROGRESS for May, page 47, it is seen that for the 0.10 carbon alloy containing 18% chromium, the ferrite is the stable phase for all temperatures. Consequently, we cannot get the range of physical properties that can be obtained with the 12 to 16% chromium alloy.

Under certain specific conditions of service in which the alloy is subjected continuously to temperatures in the neighborhood of 900° F., associated with high pressures, embrittlement occurs which is analogous to the well-known caustic embrittlement encountered in boiler plate. This brittle condition exists when the metal is cold. At the temperature of service, the alloy is quite strong and ductile. Embrittled in such service, the alloy can be rendered ductile again by heating to above 1,000° F.

26 to 30% Chromium

Chromium-iron alloys, especially those of high chromium content, show very great resistance to oxidation at high temperatures. For this purpose alloys in the range of composition carbon under 0.25%, chromium, 26 to 30%, and nickel under 0.50% are used. This composition is ferritic; it is non-hardening; its physical properties are not changed by heat treatment. It is best annealed by heating to 1,650° F. for from 6 to 12 hr. and quenching in water. Its physical properties then are:

Tensile strength	75,000 to 100,000 lb. per sq.in.
Elastic limit	45,000 to 60,000 lb. per sq.in.
Elongation in 2 in.	25 to 30%
Reduction of area	45 to 65%
Brinell hardness	160 to 200

There are two ranges of temperature within which this composition becomes brittle. At temperatures above 1,800° F. it will develop a large grain, gradually losing ductility. This brittleness cannot be corrected except by reworking the metal.

Courtesy Standard Oil Co. of Ohio

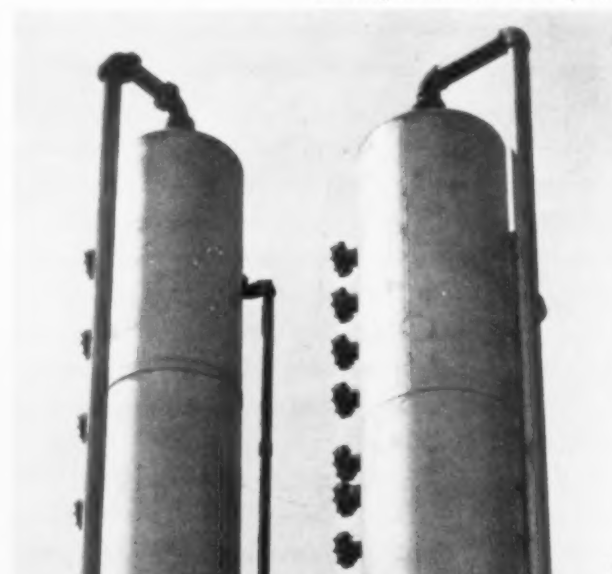


Photo by Edith Carrington

The second range is between 750 and 1,100 F. If cooled slowly through this range or if held within this range, it will be brittle at room temperature. The cause of this brittleness is not definitely known. Bain has shown the appearance of a new constituent in alloys which have become brittle, but this constituent is apparently not a carbide or a nitride, as alloys melted in a vacuum practically free from carbon and nitrogen still show this phenomenon. This brittleness, however, can be corrected by again heating to temperatures above 1,100 and rapidly cooling. For service in which these alloys are not subjected to sudden shock or vibration when cold, this brittleness is not objectionable.

Machinability of Chromium Alloys

While all these alloys can be machined quite readily, they are not suitable for parts machined on automatic screw machines where high cutting speeds are employed. For such purposes, modified alloys containing up to 0.4% sulphur have been developed, particularly in the 12 to 16% chromium range. The high sulphur content reduces the capacity of these alloys for hardening and, as might have been expected, lowers their corrosion resistance. For many applications, however, where the service is not too severe, use of high sulphur alloys may be justified.

The coefficient of expansion of the chromium alloys is about the same or a little less than that of mild steel.

With increase of chromium, the electrical resistance is increased. The 5% alloy has a resistance of about 34 microhms per c.c., the 12 to 16% about 60 microhms per c.c., and the 16 to 19% chromium iron about 67 microhms per c.c.

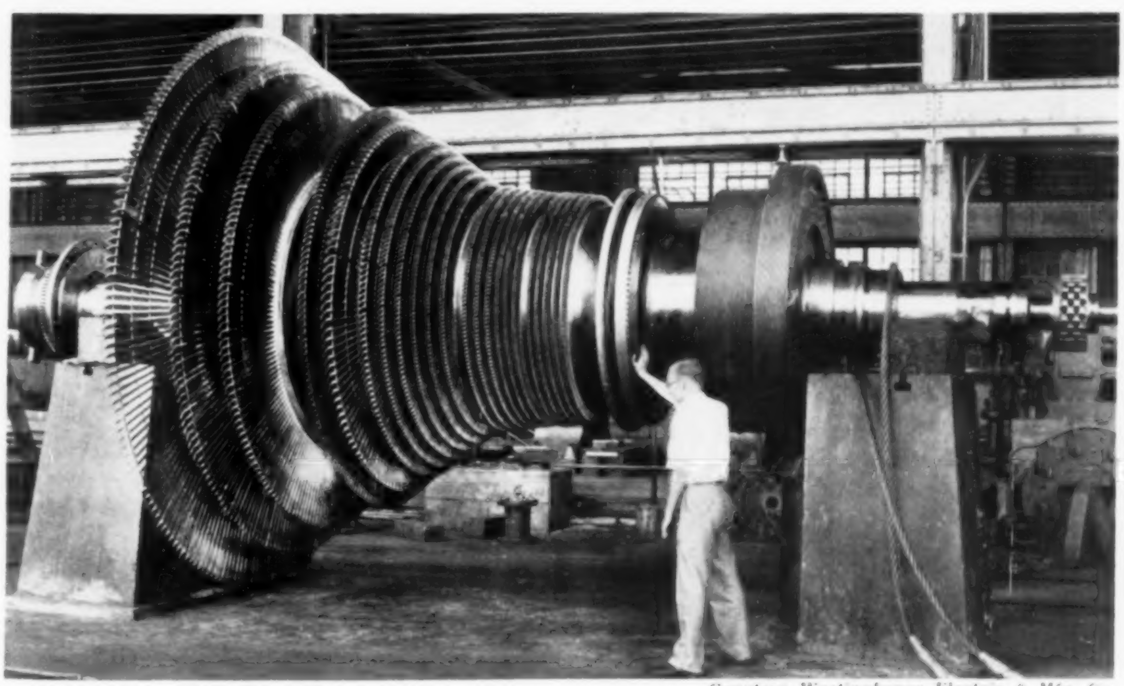
The 12% alloy resists oxidation at temperatures up to 1,500° F., the 16 to 19% up to 1,600° F., and the 26 to 30% up to 2,150° F.

They are all suitable for forming and drawing operations, although the 26 to 30% chromium alloy is not recommended for use involving difficult fabrication.

They may all be machined and welded by the usual methods.

Corrosion Resistance of Chromium Alloys

Corrosion resistance of these alloys increases as the percentage of chromium is in-



Courtesy Westinghouse Electric & Mfg. Co.

creased. F. N. Speller ran a series of tests in tap water containing oxygen in different amounts, and the results are summarized in the diagram on the opposite page.

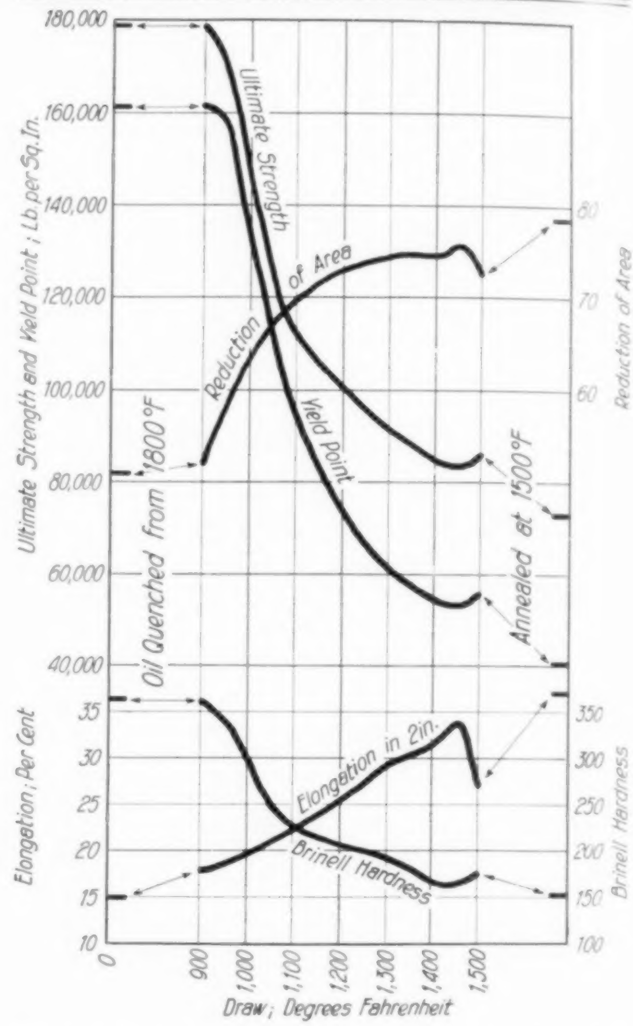
These results show that under these and similar conditions, the rate of corrosion is decreased as the percentage of chromium is increased, but that there was very little difference between the 13% and the 16% chromium alloy. Under these conditions, it would seem that the optimum benefit was obtained when the chromium was 13% or higher.

Corrosion tests run in concentrated nitric acid at 252° F. show a loss of 2.3 mg. per sq.in. of surface per hr. for the 12% alloy and 1.4 mg. for the 16% alloy. Here the 16% chromium alloys show marked superiority. It is obvious that the proper composition of alloy must be determined for each type of service and the maximum chromium content which is beneficial will be different for each type.

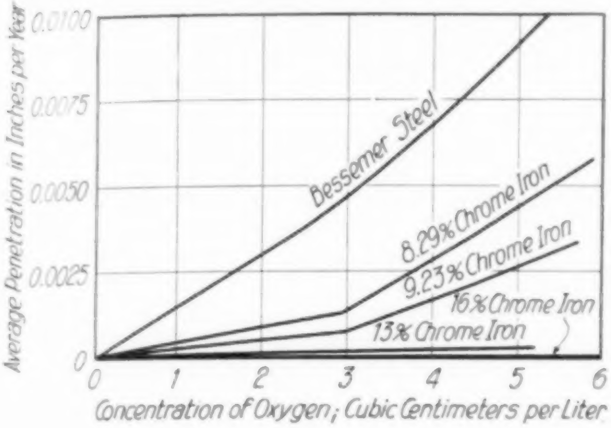
Heat Treatment is Necessary

It is necessary that these alloys be properly heat treated. If their stainless property is to be preserved, the high carbon alloys must be hardened to put the carbon in solution and tempered at temperatures which will not precipitate carbide. This is obvious, as in a heterogeneous structure of an annealed alloy the areas of carbide and ferrite would constitute minute electrolytic cells and rapid solution of the more electro-positive constituent would take place.

For the low carbon alloys (or rustless irons) we have a different condition. Although in the annealed condition, both types of alloys are ferritic and contain carbide dispersed within the ferrite grains; this amount of carbide is dependent upon the chromium and carbon content. Carbon is apparently soluble in chromium ferrite (ferrite with chromium in solid solution) up to a few hundredths of one per cent. Alloys containing less than 0.10% carbon and with 12% chromium may therefore be used in the annealed condition, but in this condition these alloys cannot justly be termed as rustless (as rust will form on their surface), but they resist progressive corrosion to a remarkable extent. Cases are known where this low carbon composition (both hardened and annealed) was exposed to the Pittsburgh atmosphere for a period of six years, and although a hard, adherent rust covered the surface, when this was removed with a polishing abrasive only a slight abrasion of the surface was apparent and no pitting had occurred. For resistance to atmospheric corrosion, it has been stated that the ferrite crystals should contain at least 11% of chromium in solid solution. However, when maximum resistance to corrosion is required of alloy containing 12% chromium and 0.10 carbon, they had best be hardened and tempered — but for many applications, the difference in corrosion between the hardened and tempered and



Physical Properties of 12% Chromium Iron. Annealed 1-in. rods machined into A.S.T.M. test pieces, oil-quenched from 1,800° F., and drawn to temperatures between 900 and 1,500° F. Rapid air cooling on small or light sections will duplicate, approximately, the results shown for oil-quenched 0.505-in. test pieces



Effect of Oxygen on the Corrosion of Iron With Various Chromium Content, When Immersed in Tap Water, According to F. N. Speller

the annealed condition is so slight as to be almost negligible.

Where it is necessary to have higher corrosion resistance coupled with maximum softness, which makes it imperative to use the alloy in the annealed condition, the alloy with low carbon and with chromium from 16 to 19% should be used. In the annealed condition, this composition shows very little carbide under the microscope. It has been stated that in order to have an alloy that is truly *rust resistant* in the annealed condition, the chromium content should be 15% plus 16 times the carbon content. This composition of the 16 to 19% chromium alloy falls within these limits. It should find wide application in the form of sheets from which articles may be readily fashioned by bending and drawing, after which they may be annealed in the usual manner.

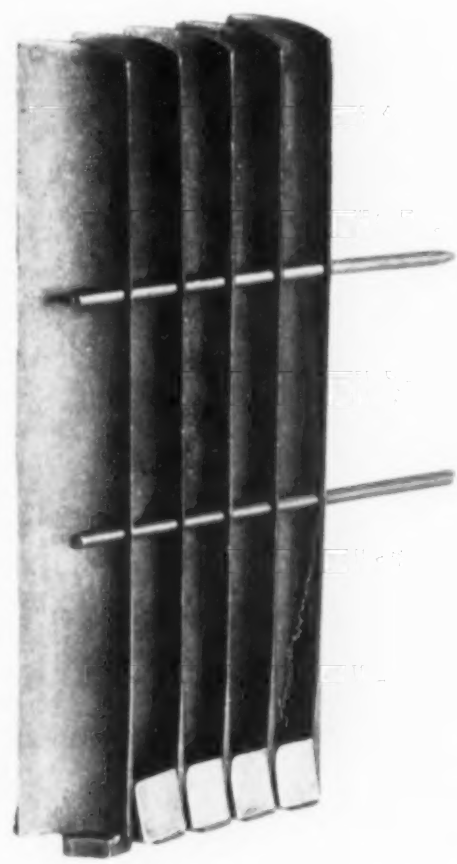
These alloys offer resistance to the attack of many chemical substances. The behavior of the 12 to 14% chromium irons, as well as the 18% chromium, 8% nickel steels, to be discussed later, is shown by the table on page 81.

Remarks on Fabrication

All of these low-carbon high-chromium alloys are quite well known and they offer no particular difficulty in handling. They are more difficult to machine than ordinary carbon steels. For drawing and press work they require more power and perhaps shorter draws and more frequent anneals. They are slightly more difficult to weld and may cause some trouble until the welder has found out by experience the proper technique for making sound welds in the material.

It should be remembered that these alloys are used under conditions where corrosion is severe and the fabricator should, as far as possible, put the finished article in the same condition as the original metal from which the article was made. Porous and oxidized sections of welds should be removed by grinding. For severe service, scale should be removed, although polishing is not necessary. In all cases, welding rod of the same composition as the material itself should be used, and it should be deposited in the weld in such a manner that the composition of the finished weld is the same as the material itself.

A Group of Reaction Blades Drawn from Stainless Iron



Courtesy of Westinghouse Electric & Mfg. Co.

By J. C. Weaver
Cleveland

MECHANICAL PICKLING

MODERN mass production methods often require automatic pickling devices which can be placed in straight line with other machinery, thus avoiding much unnecessary handling and labor. Mechanical equipment for this duty has been designed in the form of heavy duty continuous pickling machines where the immersion time may be correctly controlled and where temperature and agitation of solution can be used to fullest advantage. Now that this operation can be accomplished in the regular manufacturing line, many objections to the use of acid have been overcome, and properly cleaned material may be employed in the various forming operations — thus improving the overall production costs.

The first photograph shows such a machine, so designed that it may be entirely enclosed except for loading and unloading doors. All fumes are exhausted through a fan on top of the housing, so that bright stock in process of manufacture, adjoining machinery, shafting, lighting fixtures, and other overhead equipment will not be rusted or even discolored by escaping acid-laden steam. The photograph was taken in a large industrial plant manufacturing household refrigeration units. This equipment removes scale from deep drawn steel cylinders after they have been annealed to remove cold working strains.

As can be seen, the machine is loaded on the outside of the hood. A conveyor carries the parts into the enclosure, lowers them into and carries them through the pickle tank, the necessary time of immersion being predetermined so that all the scale will be removed without injury to the steel underneath. The conveyor then automatically raises the load of cylinders out of the acid, drains them, rinses, neutralizes, and again rinses. If subsequent operation requires it, the cylinders are immersed in oil before delivering them to the discharge end. Such a machine may have an automatic unloader for dropping the clean parts upon a conveyor for transfer to further manufacturing operations.

Obviously, this type of unit may be designed to include as many pickling, cleaning, and rinsing operations as are necessary, and may be set and made a part of the regular manufacturing line-up so no re-routing of material to a distant pickling house is necessary.

Its advantages are many: It saves floor space, saves time, eliminates excessive deterioration of building and fixtures, and transforms a disagreeable and sloppy job into a clean, orderly, and mechanically definite manufacturing operation. One may walk along the outside of this housing without being aware of what is going on inside.

Mechanical pickling equipment of this gen-

eral design may also be used for heavy material such as forgings, rim stock, disc wheels, heavy annealed drawings or stampings. Providing the proper acid is employed, such machinery is excellent for pickling iron castings.

In one manufacturing plant two men feed such a continuous pickling machine with stock used for making the lighter type of pleasure car rims, and it has pickled, rinsed, neutralized, and oiled 90 tons of metal in one 10-hr. day.

Such well-designed devices have other advantages besides eliminating the fume nuisance. When immersions are accurately timed and the solutions mechanically agitated, more of the active part of the pickling solution is used and a better metallic surface is obtained. Of course, the machine parts must be made of metals which will withstand the conditions existing inside the hood — no small problem, yet containing no impossible factors.

Many manufacturers have found that a continuous pickling machine placed in the regular production line will reduce the cleaning by at least half. Sometimes costs have been lowered to only 20% of those formerly borne by open tank equipment installed in a separate building.

In some acid dipping operations it is necessary that a quick transfer be made from one operation to another in order to prevent oxidation or discoloration. This is accomplished by a mechanism similar to the one employed on a fully automatic plating machine. In the accompanying photograph the loading and unloading end of such a machine is shown. It includes the following operations: Pickling, bright dipping, rinsing, lacquer dipping, draining, and drying.

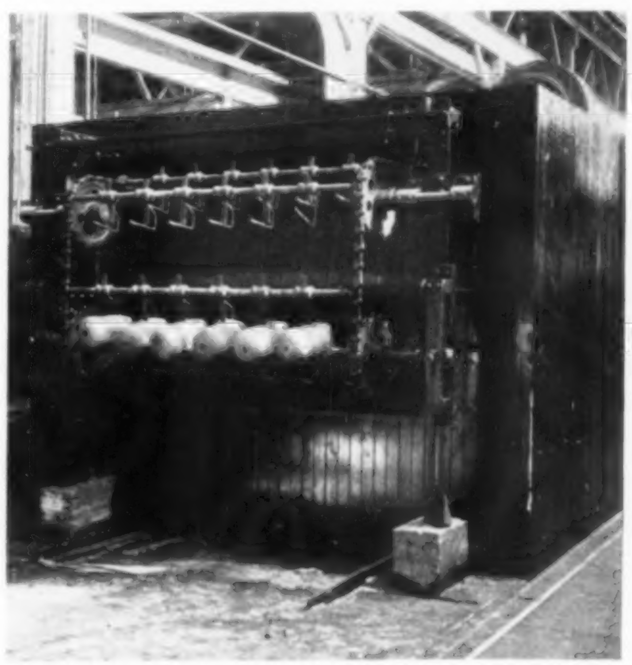
Parts are hung upon crossbars corresponding to the work rods on a plating machine. A conveyor carries these parts through the various operations where oil, dirt, grease, and scale are removed; after drying, the parts are dipped into a lacquer. The conveyor carries them back to the return end through a heated oven overhead, so that when the parts return to the loading end they are dried and ready for the assembly line.

Quick transfer devices make a full automatic machine available for an exceedingly wide range of applications, whether it be for actual preparation and plating, or only for cleaning, japanning, or lacquering of parts. Proper variations in the design adapt it for bulky or heavy parts. It obviously is adaptable for small parts placed on individual hooks or racks, such as stampings or small forgings, or smaller pieces carried through in baskets, or, at the other limit, steel boxes as large as the outer case of household refrigerators.

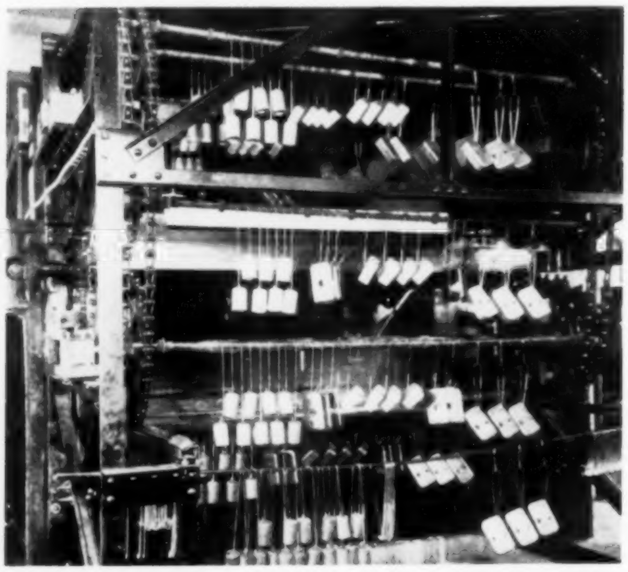
For the purpose of clear illustration, the transfer machinery is photographed without work on the racks, but the problem may be stated as "to transfer work immersed in tank *A* quickly into tank *B*." The work is hung from rack *C* which rides on rails on top the tank-sides and is propelled forward at a uniform rate by chain links *D D*.

Transfer is done by auxiliary loops of chain *E E* which travel much faster than the main conveyor *D*. In fact, the speed of transfer chain is such that it makes a complete round trip while the latter moves ahead one link. Chains *E E* carry a pair of stirrups hung from opposite links, and placed so that they pass the top of the tank on an upward trip at the moment when the work rack has arrived between the vertical chains. These stirrups pick up the extended

Wholly Enclosed Mechanical Pickling Unit May Include Any Required Number of Tanks for Cleaning, Rinsing, Drying, and Oiling. Strong fan exhaust eliminates all steam and fume



Small Parts Over Supporting Rods in Lower Part of This Machine Travel Through Various Tanks to be Cleaned, Dried, and Lacquered. On the return trip they go through an overhead drying oven and appear above the loading station ready for shipment or assembly



ends of the horizontal bar on which the work is hung, carry it up, then over, and down into tank *B*. *F* indicates such a bar en route.

Time of immersion in tank *B* can be adjusted by changing the position of sprocket wheels driving the transfer loop. At the right is one set for minimum clearance over tank-ends.

Pickling machines of these types are motor connected through a variable speed drive, which affords considerable regulation in the time of immersion in the most active solution, so that more than one class of product can be handled.

Success of every chemical and mechanical operation requires the maintenance of uniform conditions and accurate control; machine pickling predetermines the time periods. Concentrations of the various solutions and their temperatures are easily controlled, so the results on a steady flow of uniform material leave little to be desired in efficiency.

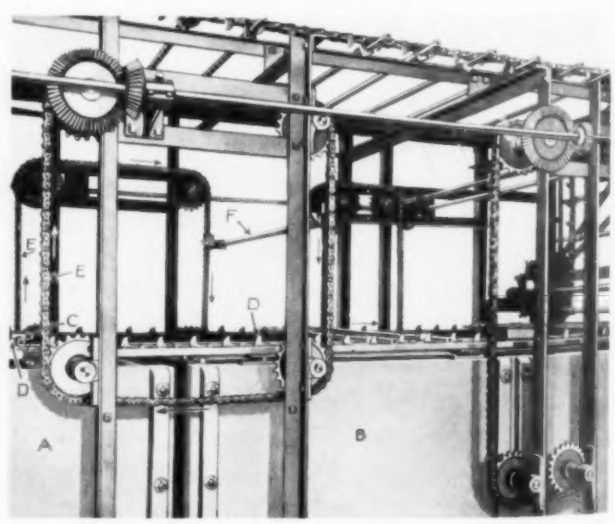
Continuous and automatic pickling machines, such as shown in the views, may be readily designed for the introduction of electric current. In certain tanks, for instance, the work racks may ride on busbars. (Bar-ends would, of course, be insulated from the driving chains.) Therefore, such units may be used wherever electro-cleaning is essential, or where it is desirable to electro-pickle the products.

Small rugged parts in quantity may be handled to great advantage in picklers built like a tumbling barrel or concrete mixer. These may be units for handling one batch at a time in a single operation; in other layouts a number of units are aligned for a continuous flow of material through successive operations.

Batch picklers are most conveniently charged by a loading scoop, exactly like the one on a portable concrete mixer. Ordinarily, the perforated drum of acid-resisting metal is cylindrical, and rotates slowly, keeping the parts moving about in the pickling bath. (The latter is contained in a lead-lined tank.) Inside the drum is a spiral rib — often nothing more than a long bar bent into a helix and welded to the inner surface. This spiral is set so that it keeps moving the work toward the loading end; to discharge the batch the driving motor is reversed and the work tumbles out of the drum into an elevator boot or a lifting cylinder.

A type of rotary machine for several associated operations is shown in the view. It is installed at the Mansfield plant of Ohio Brass Co., and is properly hooded to remove undesirable vapors. At the left is a barrel operat-

Work Approaching on Bar C Is Picked up by Stirrups on Chains E, Taken Over Tank End, and Lowered on Chain Traveling Ahead on Tank B



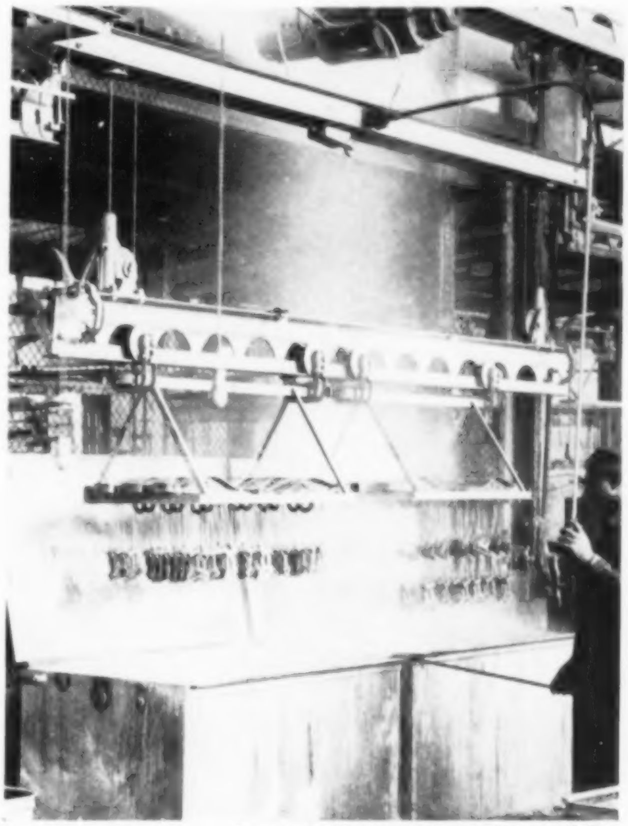
ing in a lead-lined tank, and the parts to be cleaned are tumbled with stars to speed the action. Stars are separated and returned, and the acid is constantly recirculated by a corrosion-proof pump. A rinsing screen is next in line, and discharges into a hooded washing drum.

Somewhat similar equipment for cleaning malleable castings contains two barrels in tandem. Annealing pots are discharged directly into the loading scoop and the packing material is screened out of the mixture in the first barrel and falls into a hopper-bottom leading to a conveyor. Cleaning is effected in a second barrel, and washing in a third.

Small razor parts are also handled in a line of similar equipment, capable of cleaning, pickling, washing, sawdust drying, and polishing.

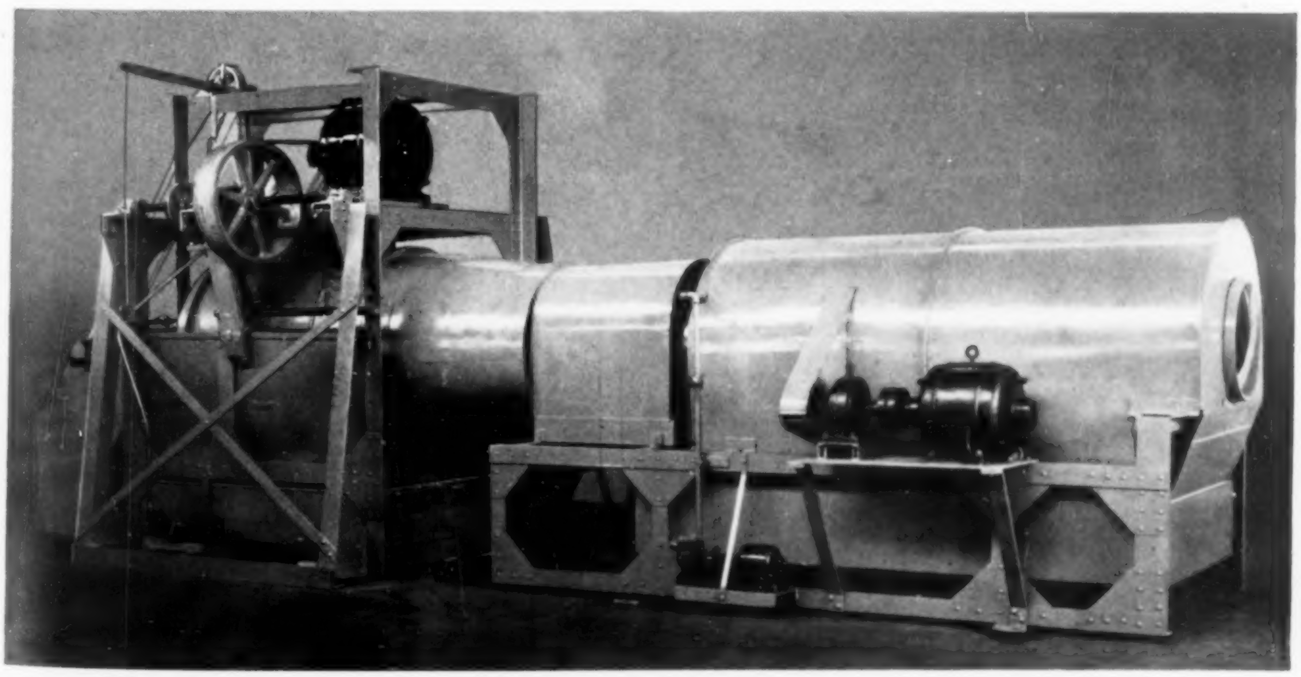
There is little doubt that mechanical pickling in appropriate equipment such as briefly described above is desirable on many counts, but it is not an economical installation for all plants. Sometimes production is not great enough to justify the expense; again, parts to be pickled may not readily lend themselves to automatic operations either *(Continued on page 96)*

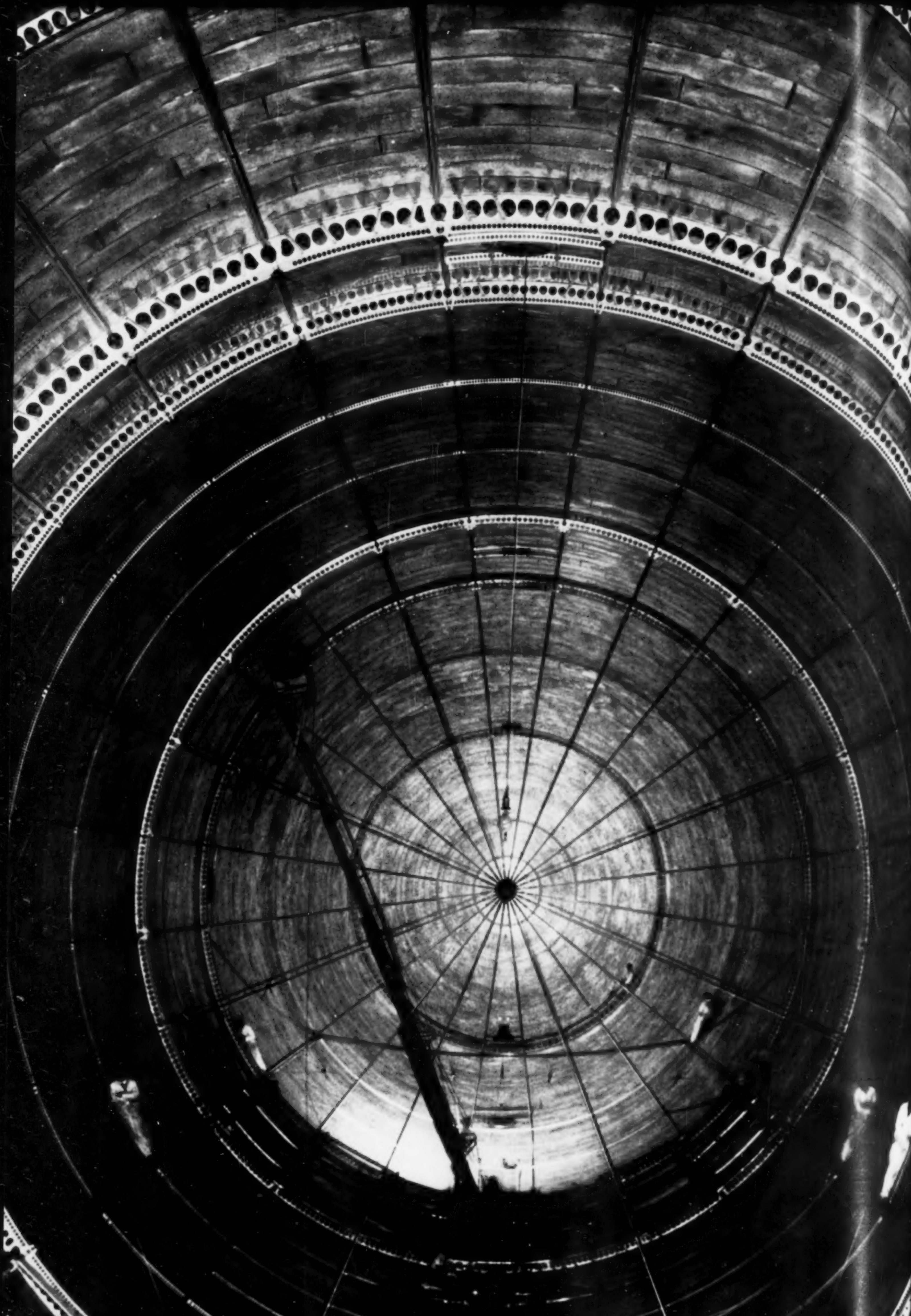
Drop Section of Overhead Tramrail Handles Several Carriers With One Hoisting Motor



Courtesy Cleveland Electric Tramrail Co.

Batch Picklers and Washing Machines May Be Arranged in Tandem and Properly Hooded. Such a combination of equipment is excellent when small parts of similar shape are to be handled on a production basis





Editorial

Small Metal Aircraft vs. Big Zeppelins

THOUSANDS of people visit the Akron hangar (25,000 on a single Sunday) to marvel at the size of the Navy airship ZRS-4 there nearly finished. Probably not one in a hundred of them has ever seen the hull of an ocean liner, partly built. Those who have cannot avoid thinking of the contrast the spidery skeleton of the one presents to the massive frame of the other. One craft depends on woven fabric to withstand the tempest; the other often finds tough steel plating all but inadequate to turn the waves.

While both classes of craft are designed to float in a fluid medium, and while any failure to float brings speedy disaster to ship and crew, the air-minded enthusiast may readily brand such a contrast as biased, not representing nearly all of the essential circumstances. Perhaps the chief point to emphasize here is that while an ocean-going ship has every appearance of staunchness, the air-going ship has an equal air of fragility.

There is little in the history of transportation to throw doubt on these appearances.

Even the densest savages know how to build water-worthy boats. Throughout the history of civilization there has been a constant increase in size, sea-worthiness, and cruising range of these craft. Consequently, the rapid development of the huge machine-driven metal ship from the sizable wooden windjammer was associated with a minimum of grief; man had learned how to swim and paddle before he had learned how to sail, and, consequently, he had some chance for his life if his machinery blew up or his ship broke her back.

On the other hand, the airship constructors act much like the child who tries to run before he can walk. Within 30 years of the first experimental flight of a small dirigible, he has doubled and redoubled the size of his craft until they become the wonder of the world. It must be admitted that some 200 airships have been built in the meantime, but it must also be said that the fingers of the hand today number the complete roll of air-worthy craft. If it were not for the miraculous Graf Zeppelin the art would have few notable achievements to credit against a sad number of disasters.

Stated baldly, bigger airships are being built when we haven't learned how to sail the smaller ones, nor how to land safely from a shipwreck.

Every failure is supposed to teach a lesson. When the English ship R-38 broke in two and fell into the Humber, designers and navigators discovered that stresses from the inertia of even a lighter-than-air ship mounted to the danger point on quick turns. When the Shenandoah was torn apart by air currents of cyclonic intensity, the designers and navigators discovered that the structure must be strengthened against unexpected differences in wind pressure, and the ship must run away from approaching storm areas. The R-101 ("an enterprise upon which years of concentrated effort had been directed by the pioneers who perished" in the words of the Court of inquiry) was a victim of leaky gas bags — a gradual loss of buoyancy in a forward bag, and an increasing accumulation within the envelope aft, sent the ship into a nose dive. What lesson that taught is probably the folly of placing so much reliance on the integrity of flimsy fabric.

Structural strength against manoeuvering and storm stresses can be built into the skeleton if the ambition to carry large loads of fuel for long cruises is resisted. Safety against deterioration or chafing of gas bag fabric is possible only by substitution of an altogether new and more permanent material.

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Mr. Hardecker, in the leading article in this issue, shows how this can be done. An inflated metal airship, sheathed in thin, aluminum-clad duralumin or thin stainless steel, with joints riveted or welded, would float as long as the shell were not riddled by bullets or seams sprung by violent buffets. The structure of such a metal-clad airship would approach an ocean liner in its fundamental design — an inner structure of heavy frames and girders would be covered by a fluid-tight metal sheath to give the necessary buoyancy. One thickness of metal would replace the complex layers of fairing fabric, shear wiring, cord netting, and gas bag of the conventional Zeppelin.

There may be some obscure fact unknown to the engineering public which limits the size of the metal airship. The builders of the ZMC-2, the Navy's example of such craft, will not admit this contingency. Of course, existing examples of the all-metal ship are small, but new ones could and should be gradually increased in lift and cruising range, and the design revised as the necessity was indicated by studies of the structure during flying in all weathers. The risk and expense of such a development certainly would be less than the plan of building Zeppelins bigger and bigger.

Some think that a lighter-than-air ship is fundamentally unsafe because "freedom from disaster depends upon maintaining an escapable gas within a defined space." A similarly worded criticism might be leveled against the steel ocean liner. Success has been attained in the latter instance by designing ample strength into the hull, despite the wish to steam long distances without refueling and to carry heavy pay loads. We may have better luck with our aircraft when we think less of long cruises and more about a simple and strong metal hull.

AMONG the amusing frailties of the human race is the belief that arises in the minds of many an eminent citizen that he, being an authority in one branch of endeavor (such as making automobiles or directing an orchestra) is also worthy of credence when he issues pronouncements and prophecies on other things (such as the art of writing history or the propriety of light-colored evening attire).

Gustav Lindenthal is the latest victim of this obsession. If the question were "bridges," his opinion on the economics of a certain design would be worth a consulting fee; his judgment on spans and foundations still is good, despite the 81 years which reduces most men to senility. Happily his reputation as a bridge builder does not rest on his views about our resources in iron ore and carbon. Recently he said — possibly led on by reporters who wanted a story about the great man:

Bridge Expert Predicts Doom of Steel Age

"In half a century, perhaps, New York will rise a great, white, shining city, such as the world has never known, and men will be more at peace there than anywhere on the earth. But I know what will happen in 200 years. New York will be like a ripe apple. All things must ripen. And then New York will drop away. Its vast population will move southward. There will be no coal to keep the millions warm here. All of this that we are building will mean nothing except something for men to remember for a thousand years — the great steel city. Its climax will be the climax of the Steel Age. . . . There will be no more ore, no more steel."

Old men are prophets, and his prophecy may be correct that within 50 years the politicians of New York will solve the subway transportation problem so the inhabitants *can* live at peace. Lindenthal gave the politicians the benefit of a doubt which he evidently denied to the engineers. The latter gentry are living in the well-founded hope that long ere any great shortage of domestic coal, the ordinary home will be heated with gas, oil, or electricity.

Whether this will happen or not one should not say unless he is a public utility expert, but of one thing any metal man can be certain: Civilization will not suffer from any lack of steel in 50 years, or 1,000 years, or 50 times 1,000 years! If New York moves South (which part of it does now, every winter) it will be for

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some other reason than that the builders cannot buy any more steel beams and columns. Lindenthal had probably read a statement somewhere that the Missabe range will be worked out in 30 years. What that statement meant is that the present reserves of proven ore of the grade now being mined are only 30 times the annual production. It has no relationship whatever to the amount of iron in Minnesota.

When any man says that there will be no more iron ore available in 2131 A.D., he forgets that the earth's crust contains 5% of iron, and that its core is probably an enormous meteorite made of about 90% iron. In fact, iron, next to silicon and aluminum, is the most common metal we have on the surface. How we can ever have a shortage of iron or steel (other than a local or temporary shortage) any more than we could have other than a local or temporary shortage of sand, is hard to imagine.

Just now, in the relatively early years in its development, the iron industry is mining the high grade deposits. Soon these bonanzas will be exhausted, as are most of the known bonanzas of gold, silver, and copper. Then it will be necessary for the industry to mine slightly lower grade, and either revise the melting processes to handle it directly, or change the ore ("beneficiate" it) by mechanical or chemical means so that it can be smelted by current processes, or do both of these things. Rest assured that these things will be done, and as the iron content of workable ore is reduced by these improvements, the tonnage of the available material increases in geometric ratio to astronomical figures.

Stated in another way, the word "ore" means different things at different times and places. Ore is material which is capable of being worked on a commercial scale for its metal content. Whether or not a mineralized deposit can be classed as ore in the above sense depends upon its known size and depth, its proximity to coal or other energy, to market, and to existing smelting plants, as well as upon its average chemical analysis and the selling price of the metal to be won. Obviously a deposit which is now just outside the classification of "ore" may be workable tomorrow, through a change in one or more of the variables in the list given above.

This has happened so often in the history of iron mining, gold mining, copper mining, zinc mining, that it undoubtedly will continue to happen as long as organized society exists on this earth. What man needs he gets. He will get iron and steel as long as he remembers how to dig the paint rock, char the wood, and harness the waterfall.

Iron, Steel or Brass

ALLOY nomenclature is in a terrible mess. Mr. Becket remarked at the recent Iron & Steel Institute meeting that more than a dozen authors have painstakingly explained that alloys called "rustless irons" or "stainless irons" are in reality steels. Nevertheless, the trade keeps using the incorrect terminology as an easy way to distinguish the low carbon alloys, readily drawn and stamped cold, from the higher carbon alloys used in the quenched and drawn condition. And as long as the doctors of metallurgy cannot agree on a concise definition of "steel," or "alloy steel," the trade cannot be blamed unduly.

Literature of the art and science of metals tends to follow the usage of its practitioners. No matter how much a writer or an editor may believe that a chromium-molybdenum steel should be spelled that way, sooner or later he will fall into line with his associates and say (and write or print) chrome-moly. Nor is that tendency altogether to be condemned. The English language is a living, growing thing—for which Heaven be praised. Words are constantly being adapted to current usage; the slang of today only needs to be used by a Nobel prizeman and it becomes fit for the dictionary.

Hence it is that "brass," which to a purist would mean a series of copper-zinc alloys (and a little tin or aluminum wouldn't make it a bronze, either), to the world means any yellowish metal. In bonny Scotland it means cash. To gentlemen of the old school it means impudence. To a musician it means horns. To a railroader it is bearings. And they're all right!

By Charles Pack
Consulting Engineer
New York

DIE CASTING

brass and other new alloys

DEVELOPMENTS in the die casting art, as noted in an editorial in April METAL PROGRESS, may be expected in the near future.

In order to grasp the full significance of these developments and appreciate their commercial aspect, it is advisable to outline the present status. Fortunately, there are available the unbiased records of tests made on commercial die castings by A.S.T.M. Committee B-6.

During the last three years this committee has examined some 80,000 test bars submitted by six leading producers of die castings. Although the work is not yet completed, the status of the present die casting art is disclosed by its published reports:

1. Die castings are being produced from two types of alloys: Zinc base and aluminum base. A small amount of tin base and lead base die castings is also being produced, but the application of these alloys is so limited that no tests of these alloys were on the program.

2. Of the zinc base alloys tested, the alloy that was found most suitable for commercial use was that consisting of 3% copper, 4% aluminum, 0.1% magnesium, and the balance high grade zinc (purity of 99.99 plus). The useful properties of this alloy were materially reduced by contamination with impurities measurable in hundredths of one per cent. Even so, none of the zinc base die castings tested were absolutely stable; all were subject to some deterioration and aging, evidenced by a reduction in the tensile properties of test bars and by an actual increase in dimensions. Zinc of exceptional purity is needed to minimize this trouble in the castings.

3. Aluminum base die castings cannot be produced commercially without excessive iron contamination. Tentative A.S.T.M. specifications, based on the consensus of leading American producers, permit up to 2%, and, in most instances, 2.5% of iron. It is the writer's opinion that analysis of aluminum die castings in use commercially will disclose many containing much more iron than this limitation.

4. Die castings are subject to varying degrees of porosity. Visible blow-holes may be expected, in most instances of sufficient size to affect the physical tests materially, and the fluctuations in the results obtained with test bars made by the same producer, from any given alloy, can be attributed to their presence. Extent of these blow-holes on so simple a casting as the standard die cast test bar, shown

in the accompanying view, is shown particularly in the report of Dr. St. John on X-ray examinations of the test bars, reported in *Transactions*, A.S.T.M., 1929.

5. No magnesium base or copper base die castings were being produced commercially in this country, and this group of alloys was not considered in the program.

In the writer's opinion, this is an accurate summary of the industry today; in contrast, he will now endeavor to outline the die casting industry of the future, and present some data to indicate the extent to which this ideal is already realizable.

Being essentially a casting, a die casting is often viewed by the layman as a metallurgical problem. On the other hand, the writer has often pointed out that in the die casting art, the mechanical phase is paramount to the metallurgical. Any broadening of, or improvements in, the metallurgical phase of the die casting art must be preceded by a further development of the mechanical phase of that art which would tend to remove the restrictions which the mechanical phase of the art now imposes upon the metallurgical. Stated in simple terms, the present types of die-casting machines limit the choice of alloys that may be cast by this process, and no vital development in the process can be expected until these limitations have been removed.

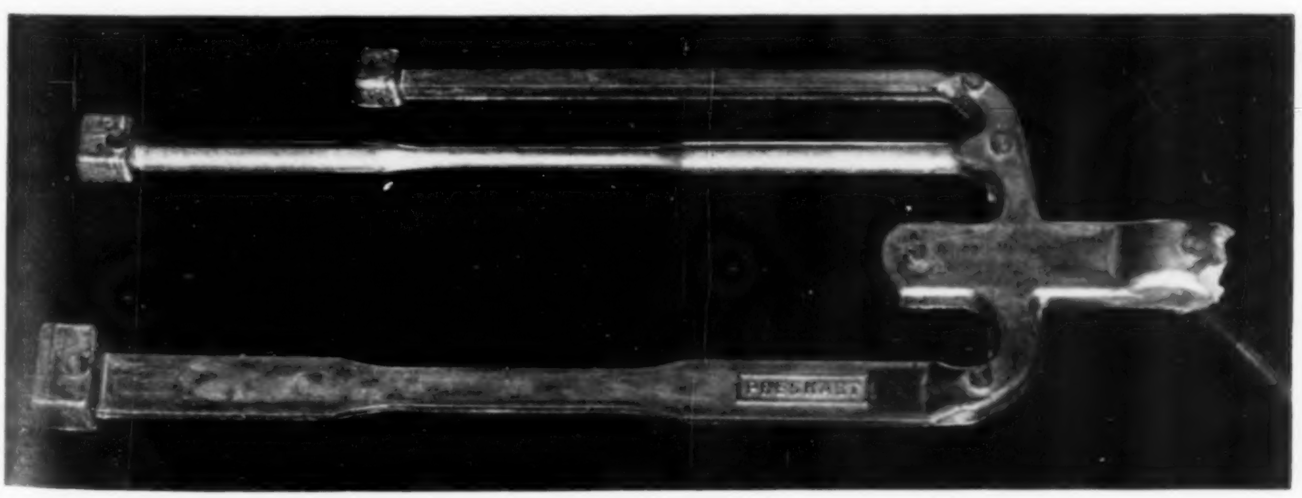
Furthermore, the die casting process has long been regarded as a mysterious one, limited to a few special alloys developed to conform to the process. The picture that the writer wishes to present of the future, is of a method of casting that has no greater limitations than has the sand foundry. Furthermore, a die casting, inherently benefited by rapid chilling in the mold, should be able to use a large variety of alloys having no commercial value as sand castings.

Zinc Base Alloys

It has already been stated that all zinc base die castings are subject to varying degrees of deterioration and aging in service. Since no such phenomenon is encountered with metallic zinc, even of the lower grades, the question naturally arises as to the cause of this deterioration of zinc base die castings. It has been definitely proven that the process of casting does not induce this deterioration of the resultant product, but that it is caused by the alloying elements added to the zinc, the most harmful of which are required by the primary requirement of a die casting alloy, namely, that it function properly in the casting machine.

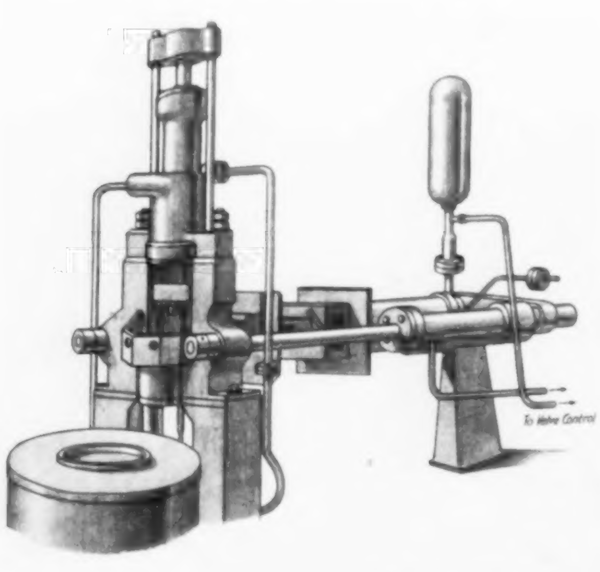
Aside from the problem of permanence, there has been considerable controversy over the strength of zinc base die castings. Some

Test Bars, Dimensioned According to A.S.T.M. Standards for Die Castings, Cast of Pure Zinc and Other Unconventional Alloys



of the A.S.T.M. tests show ultimate tensile strengths of 50,000 lb. per sq.in. Tentative A.S.T.M. specifications call for a minimum tensile strength of 35,000 lb. per sq.in. as cast, and 30,000 lb. per sq.in. after exposure to water vapor at 95° C. for 10 days. It is not at all difficult to produce die-cast *test bars* from a number of the present zinc base alloys that will meet these specifications, but from the writer's experience with commercial *castings*, he is of the opinion that the engineer who attempts to design zinc base die-cast parts on the basis of 30,000 lb. per sq. in. will be disappointed with the results. Until the producer is in a position to deliver uniform castings, reasonably free from blow-holes, until the permanence of the alloy becomes independent of microscopic amounts of impurities, the engineer cannot use a zinc base die casting where the part is subjected to any severe strain or shock, or must retain its size within reasonably close limits.

Sketch of Die Casting Machine Developed Abroad by Joseph Pollak. Metal is held at proper temperature in a pot of refractory materials shown in the left foreground. A proper amount is ladled by hand into a container holding sufficient for one casting. This is closed and hydraulic pressure applied by the vertical cylinder, forcing it into the die. The latter is in the center of the horizontal machine, and is held closed by the hydraulic ram at right



The opinions of a number of users, as gained in personal conversation, may be summarized as follows:

1. Use of zinc base die castings is seldom influenced by the strength of the casting; it is ordinarily adopted because of its lower cost.

2. A zinc base die casting that would not be subject to deterioration and which would have uniform, dependable properties, would be preferable to present alloys of higher tensile strength yet with unstable physical properties.

3. Zinc base die castings are seldom if ever used where the part is subjected to severe shock or strain.

4. The biggest limitation to the further use of zinc die castings lies not in the physical properties of the present alloy when properly produced, but rather in the unreliability of the resultant product from that alloy.

It was noted above that the alloying elements which cause the trouble in zinc base die castings are added to make the alloys more workable in the conventional machines. Given a die-casting machine that will cast *any* zinc base alloy, we may reasonably expect a number of zinc base alloys that will be permanent and dependable in their physical properties when made into die castings.

With this possibility in mind, the writer devoted himself to developing a machine free from all restrictions with regard to the composition of the alloy that may be cast. It seemed possible to do by extra high pressure what the present machines achieve by extra high temperature. As a preliminary experiment with a machine designed according to this principle, ten zinc base alloys were cast, of analyses entirely different from those included in the A.S.T.M. tests. Pure zinc was one of them and proved entirely satisfactory.

A number of them proved entirely stable under all the tests used now to indicate instability of dimensions, and they could therefore be used in the finest precision instruments, or where the parts may be subjected to the continued action of water or steam. Included in this preliminary group of alloys was one that showed a tensile strength of 60,000 lb. per sq.in. with a lower rate of deterioration under accelerated test than any alloy tested by the A.S.T.M. committee.

A Group of Brass Die Castings Produced in the Pollak Plant, Prague, Czecho-Slovakia

Whereas the castings obtained in this preliminary experiment were not microscopically perfect, the test bars were commercially solid; they disclosed no visible blow-holes. Test bars made from pure zinc were rolled into thin sheets and drawn into wire without any difficulty. Furthermore, it was found possible to machine into the center of the round or the square (impact) test bars and polish and plate these test bars without any visible evidence of pin holes.

The results of the foregoing tests have established that it is possible to produce zinc base die castings commercially that are sound and will not "grow" in the least or warp in service. Zinc base die castings may also be produced from any composition that is sufficiently free from "hot shortness" to withstand the shrinkage strains.

Aluminum Base Alloys

In order to demonstrate the possibility of casting aluminum of high purity, test bars such as shown in the illustration were cast from grade A aluminum ingot. These had a tensile strength of 16,000 lb. per sq.in. and an elongation in 2 in. of 31%.

One of the most useful of the aluminum alloys consists of 13% silicon and the balance aluminum. It is used extensively in sand foundry and permanent mold practice, as well as for die casting. Iron is particularly harmful in this alloy, greatly reducing its ductility. On this alloy the following physical properties were obtained in die cast test bars: Tensile strength, 44,440 lb. per sq.in.; elongation, 4.5% in 2 in.

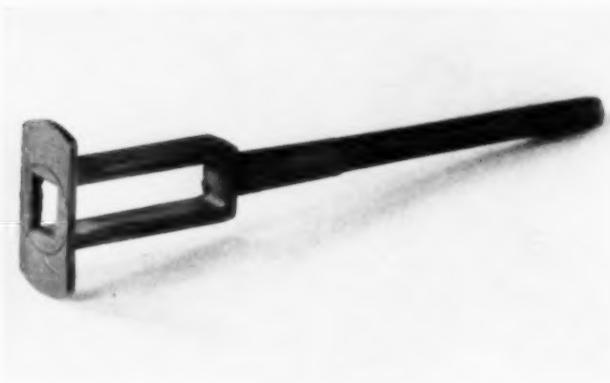
This alloy was made by merely dissolving the silicon in the aluminum; none of the so-called modifying agents were used.

For the purpose of comparison, the results obtained by Committee B-6 of the American Society for Testing Materials on die-cast round test bars made from this alloy may be quoted.

Producer	Tensile Strength	Elongation
1	29,680	1.36%
2	36,260	1.79%
3	26,505	1.53%
4	30,734	1.1 %
5	33,070	1.8 %

Die castings were also produced from the well-known "Y" metal used so extensively in aircraft construction. The metal was obtained from the British Aluminium Co. in the form of alloy ingots.

Physical properties of this alloy, cast in



Small Cores Intersect at Right Angles

permanent mold, are given by Jeffries and Archer *(The Aluminum Industry)* as follows:

	Tensile Strength	Elongation
As cast	32,000	1%
Heat treated	37,000	1%

Die-cast test bars made in the experimental machine tested as follows:

	Tensile Strength	Elongation
As cast	38,260	3.4%
Heat treated	52,370	5.0%

From the foregoing results, it may be stated that:

1. Aluminum base die castings can be made from any aluminum alloy now used in foundry and permanent mold practice.
2. Iron content may be controlled.
3. With proper gating and venting, the "strong" aluminum alloys may be die cast and heat treated.
4. Die casting at high pressures produces parts far superior in physical properties to castings produced by any present method.

Magnesium Base Alloys

Through the cooperation of Dr. J. A. Gann of the Dow Chemical Co., it was possible to determine the casting properties of the most useful commercial magnesium alloys. These varied in magnesium content from "M," containing 98% to "B" with approximately 88%. They showed the physical properties shown in the table at the top of the next column.

Alloy	Tensile Strength	Elongation
M	25,370	11.6%
H	26,270	9.3%
F	28,332	7.8%
E	26,100	4.5%
A	32,523	5.1%
G	32,070	2.8%
B	28,500	0.7%

No difficulties were encountered in casting any of the alloys submitted. Magnesium base alloys can evidently be cast by this new process as cheaply as aluminum alloys can be cast. This is of particular significance in view of the fact that the process for producing magnesium has been developed to such an extent that the metal can be purchased for little more than aluminum on an equal volume basis.

Cadmium Base Alloys

Cadmium occupies a unique position in the metal industry, and it is doubtful if its importance has been fully realized. In the writer's opinion, cadmium offers at least a partial substitute for tin in the die casting industry.

A certain amount of tin base castings is being made now in preference to the lower priced zinc base die castings, because the former are absolutely stable, are non-corrosive, and have a low melting point (which permits casting to a higher degree of accuracy).

It is interesting to note that cadmium base alloys possess all of the above advantages with physical properties excelling those of the tin

Gate of Seven Brass Die Castings Measuring 13 In. Across, Rivaling in Size and Complexity the Best White Metal Parts

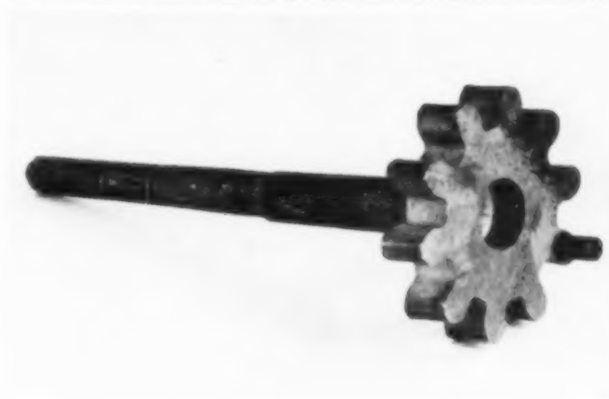
base alloys. The tensile strength of commercial tin base alloys seldom exceeds 12,000 lb. per sq.in., and alloys showing this tensile strength are generally quite brittle. In this preliminary program we have had no difficulty in die casting cadmium base alloys having a tensile strength of 25,000 lb. per sq.in. with an elongation of 15%. Doubtless higher strengths can be obtained by sacrificing some ductility without approaching the brittleness of commercial tin base alloys.

At the present moment the market value of cadmium is higher than that of tin. However, the present market price of tin is generally conceded to be well below its normal selling price. Furthermore, we are dependent almost entirely on foreign sources for our supply. Any interference with ocean shipping immediately affects the supply. Many of us have not forgotten the soaring prices in the American tin market when a few English freighters were sunk by the German "U" boats during the War, even during our period of "neutrality."

Cadmium, on the other hand, is largely a by-product of American electrolytic zinc, and it is safe to assume that the supply will increase. Consequently, lower prices for cadmium may be expected in the future, and under normal trade conditions it may reasonably be expected that the market price of tin will be higher than that of cadmium.

Under these circumstances, the future position of cadmium as a tin substitute can be readily understood. The die casting industry must regard this metal as an important factor in the future of the industry.

Brass Die Casting, End Gated, Having Parts With Thick and Thin Walls and Requiring One Long Side Core, ¼ In. Diameter



Brass Die Casting with Steel Insert

Copper Base Alloys

In a paper read before the A.S.T.M. in Detroit in April, 1930, entitled "Advance in Die-Cast Metals for Automotive Use," the writer emphasized the fact that brass die castings were being commercially produced throughout Europe. The machine referred to in that paper was developed by Joseph Pollak of Prague, Czecho-Slovakia, and the brass die castings shown in the illustration on page 75 were produced in the Pollak plant. More than fifty of these machines have been installed abroad during the last 12 months in the plants of such outstanding companies as Fiat Co., Italy; Fry's, Limited, England; Injecta Co., Switzerland; Robert Bosch, Germany; Svenska Metalverkes, Sweden; and Nikko Copper Works, Japan.

Although the die casting art is essentially an American production process and the present industry is the development of American mass production methods, it must nevertheless be recognized that true die casting of brass was first commercially demonstrated in Southeastern Europe, and furthermore, that six countries in Europe and even Japan were producing brass die castings on a commercial basis some years before any American producer was willing to admit that it could be done.

About a year ago, a large American manu-

facturer with an English subsidiary found that the foreign plant was producing some parts at a much lower cost than the American plant. Upon investigation it was found that the English were using brass die castings purchased at home. Samples were procured and sent to the leading die casters in this country, but in every instance they said they were unable to produce these parts in brass. This company was thereupon forced to import these brass castings.

Some experiments have been carried on recently by the writer in a machine that differs in principle and construction from the machine mentioned in his A.S.T.M. paper of April, 1930, and which he hopes to describe as soon as patents are covered. A lead-free brass (60% copper, 40% zinc) produced test bars having an ultimate tensile strength of 72,000 lb. per sq.in. and an elongation of 24% in 2 in. No additions of iron, manganese, or other elements (other than deoxidizers) were used in this alloy. The results are probably the best ever obtained with a 60-40 brass casting.

The same brass with the addition of 2% lead (60% Cu, 38% Zn, 2% Pb) had a tensile strength of 55,000 lb. and elongation of 15%.

No difficulty was experienced in casting the higher copper alloys such as the American Brass Co. "Everdur" (approximately 95% copper), but from a commercial standpoint the process is probably limited at present to the 60-40 brasses or such other copper base alloys that may be cast at a temperature not in excess of 1,500° F. Suitable die materials have yet to be found which will withstand the thermal strains set up in the casting of copper alloys of higher melting point. It may be definitely stated, however, that equipment is now available which will permit pressure casting of any copper base alloy, including pure copper, when the limitation of the die material is removed.

The Ideal Copper Base Casting Alloy

Whereas satisfactory results have been obtained with the 60-40 brasses, there are many objections to their use in pressure casting, one being the tendency for zinc oxide to deposit on the die surface. This oxide tends to interfere with the proper flow of molten metal and often causes a rough or pitted surface on the castings.

Close-Up of Brass Die Casting, Before Cleaning, Showing Condition of Surface and Fins

As a result of a series of experiments carried on with the cooperation of the techincal staff of the American Brass Co., die castings were produced from an alloy whose properties may be stated to be as follows:

Tensile strength	95,000 to 97,000 lb. per sq.in.
Elongation	5 to 10% in 2 in.
Hardness	150 to 200 Brinell.

This alloy, although containing over 80% copper, can be cast at a temperature below that of a 60-40 yellow brass. It has no visible tendency toward depositing zinc oxide on the die surface, and the castings have a dense, smooth surface that compares favorably with the best white metal die castings. Full information on the nature of this alloy will doubtless be released by the American Brass Co., as soon as the patents situation is covered.

Several views of brass alloys cast in the machine developed by the writer (in an effort to approach the truly "universal" pressure casting machine) are shown. There should be no limitation as to *size* of casting. In one figure is shown a gate of brass castings produced by this process that measures over 13 in. across its extreme points. Although this gate consists of seven individual castings, it forms an integral unit, and for the purpose of this discussion may be considered as such. *(Continued on page 100)*

By T. S. Fuller
Research Laboratory
General Electric Co.

ENDURANCE

of alloy steels in steam

IN THIS CONTRIBUTION for the American Society for Steel Treating's September meeting in Boston are reported the endurance properties of some well-known steels in air and in steam at commonly encountered temperatures and pressures. It is an extension of work reported to the A.I.M.E. in 1930, and was done in machines designed by C. E. Weaver which are a modification of the White-Souther and McAdam types. Each is driven directly by an individual 0.5-hp., 115-volt d.c. motor, running at a speed of 2,200 r.p.m. The temperature was measured by a mercury thermometer, and the pressure by a steam gage. Endurance limits have been determined in some instances on the basis of 10 million, and in others on the basis of 50 million cycles.

The materials were received in the form of bars one inch in diameter and about 12 ft. long. Two tensile specimens were taken, one from one end and one from the center of each bar, the remainder being cut into short lengths for endurance specimens. After heat treatment the specimens were carefully machined, special precautions being taken to remove the metal from the reduced section a little at a time in light cuts to avoid disturbing the structure underneath the surface. The final finishing on the reduced section was done with a Norton grinder, which was provided with two formed wheels to produce the exact contour of the specimen. The wheel performing the rough finishing operation was known as No. 60K Crystollon, and the one employed for the final finish was 400-grain Grade 2 Crystollon shellac wheel, both being furnished by the Norton Co. A lubricant, also made by the same company, known as "economy grinding lubricant," was used.

A comparison of results obtained with nickel steel specimens finished by this method of grinding with those of specimens of the same material prepared with 00 emery showed a variation of less than 3%, which is less than the experimental error.

Steels tested are listed on the Data Sheet, page 81. Two series of tests were made on 3.5% nickel steel, three on a non-corrodible 12½% chromium-iron alloy, three nitriding steels (heat treated before machining). Three specimens of 18-8 austenitic steel were given nine heat treatments each before testing, some running to 500 hr. in duration.

The specimen is arranged as a rotating cantilever beam, the reduced section of which is similar to McAdam's type C specimen described in *Chemical and Metallurgical Engineering* in 1921. The maximum stress is in the plane whose diameter is 0.4687 in., although the stress from the bottom of the fillet over a distance of 1½ in. therefrom varies only 1½%.

The method of test has been to load the first specimen of a series to be tested under a

given set of conditions with a stress calculated to cause failure in a comparatively short time. The load of successive specimens was then decreased in decrements of 5,000 lb. per sq.in. until a stress was found at which the specimens withstood 10 million or 50 million cycles without fracture. Endurance limits were determined from these data.

Endurance limits have been determined with the specimens in air at room temperature, in air with a jet of wet steam directed at the highly stressed section, at a temperature of 170° F. in an atmosphere of steam and air, and in steam at the five indicated temperatures.

The air-room temperature and the air-steam jet tests were made in a machine to which no steam box was attached. The latter condition was particularly severe because of the presence of both liquid water and excess oxygen, the two substances necessary to cause ordinary ferrous corrosion. All other tests in steam were carried on in machines equipped with steam-tight boxes surrounding the specimens and the corrosion was not severe. The effect of the corrosion taking place in the 170° F. steam-air equipment was of about the same magnitude as that in the air-steam jet tests.

Referring to the values given on page 81 for nickel steel, the damaging effect due to the corrosion caused by the presence of both liquid water and oxygen at a somewhat elevated temperature is well illustrated by the drop in endurance limit in the steam jet experiment to 50% of its air-room temperature value.

It is further interesting to compare the values of 23,000 and 21,000 lb. per sq.in. obtained with nickel steels *A* and *B* in the steam jet in atmosphere, indicating that where the corrosion is severe, the initial tensile properties of the material are not of great importance.

The pre-corroded specimens were heated in the absence of stress for one week in an atmosphere of wet steam and air and then tested under the conditions indicated. The results further emphasize the fact pointed out so many times by D. J. McAdam, Jr., that corrosion without stress is very much less damaging than corrosion with stress. Furthermore, the pre-corroded *B* value of 14,000 lb. per sq.in., in the steam jet-atmosphere experiment, is the lowest obtained in the tests under consideration.

The facts and data set forth are in accord with the following conclusions:

Nickel steel *B*, and non-corrodible chrome-iron alloy treated for intermediate properties were not adversely affected, in the absence of appreciable quantities of liquid water and oxygen, by steam atmospheres up to and including pressures of 220 lb. and temperatures of 700° F.

Due to the presence of liquid water and oxygen, the steam jet-atmosphere endurance values of these steels were but 41% and 54% of the corresponding air-room temperature values.

As evidenced by the steam jet-atmosphere tests of the nickel steels, if the corrosion be severe, the endurance values are not a function of the initial tensile properties of the material.

A comparison of the steam jet in atmosphere and pre-corroded air-room temperature values of nickel steel *B* further emphasizes the damaging effect of the simultaneous presence of stress and corrosion.

A chromium plate offered considerable protection to steel *B* against the corrosion of the steam jet-atmosphere test.

No damaging effect of the pre-corrosion treatment on the chromium iron was evidenced by any of the four tests carried out thereon.

The ratio of the air-room temperature endurance limit to ultimate strength was higher in the case of the nitrided nitriding steels than in that of any of the others tested.

A marked tendency of the endurance values of the nitrided nitriding steels to drop off with increasing temperature was observed.

The ratio of the steam jet-atmosphere to air-room temperature endurance values was higher in the case of the nitrided nitriding steels than in that of the other steels tested.

The 60-lb. 300° F. steam endurance value of notched nitrided specimens ranged from 74% to 83% of that shown by corresponding unnotched specimens.

The endurance properties of the 18% chromium 8% nickel type of alloy are seriously affected by long intervals of time at temperatures of 1,200° F. and above.

In the hot rolled condition the endurance values of this alloy bear a relationship to carbon content. This relation, however, disappears after drastic treatment at elevated temperatures.

Correspondence and foreign letters

Nick-and-Break Tests Valuable to Study Metal

Paris, France.—"Nick-and-break" tests have been used since time immemorial to prove the quality of metals and alloys and to detect their physical defects. It is still used to a great extent by skilled workmen in the metal manufacturing and consuming industries. Micrographical and macrographical methods have ousted it from the laboratory; the results of these more recent tests are better defined and can be more easily compared, and their interpretation is less complex and less subject to the individual's viewpoint.

It should be remembered that micrographical and macrographical appearances depend only on the metal and its heat treatment, whereas the appearance of a fracture is also a function of all the circumstances that provoked the break, and also of the form and dimensions of the part. Therefore, the present popularity of microscopic investigations must not obscure the special and valuable advantages of examining the fracture of a test piece. Indeed, the latter is, in most cases, a first-class source of information.

Since the interpretation of the nick-and-break test is complex, its advantages will be profitable only if two conditions are met:

First, the study must be made by a well-informed and a well-trained man, whose competency and impartiality are beyond doubt. This is the more necessary because the results of such a qualitative study cannot be expressed in reproducible figures.

Second, the interpretation of the characteristics found after examination of the fracture requires a coordination with information given by other research methods: Chemical analysis, micrography, macrography, and a study of the metal bordering the fracture by means of localized physical tests (for instance, hardness by indentation or scleroscope).

Even if the interpretation of the fracture is sometimes rather complicated, it may frequently have some countervailing advantages arising from the ease with which the specimen may be prepared. Plane polished sections require mechanical operations difficult to perform on very hard pieces. Thus it is that fracture tests are most often made on hardened but not tempered steels; a fracture is also used to estimate the case depth of carburized steels. The so-called Metcalf test is still the best qualification test for high carbon tool steels; to a skilled eye much valuable information is obtained from fractured bars of a given section, hardened at increasing temperatures.

Nick-and-break tests are also best to study the effects of minor surface imperfections or of minor physical defects or fractures within the body of the steel. Many internal defects cannot be shown by transverse sections of the piece. Small stringers or internal bursts would not be shown unless these defects were straight or a plane surface (which is quite unusual) and at the same time fell exactly within the plane of the section, and this may happen very seldom. Moreover, the polishing operation has a great chance of removing the very defect which is to be examined.

For all these reasons the study of a fracture will be particularly effectual to disclose parting planes of submicroscopic width and such other

Foreign Letters

matters as forging checks, hardening cracks, snowflakes, hairlines, or ghost lines.

It will also often show that the defect disclosed was formed when the metal was at a temperature or in a physical state different from the conditions under which the fracture occurred; thus the age of defect becomes known, and this is often sufficient of itself to discover its true origin.

The study of fractures may also be divided into two categories depending on the metal and on the conditions under which it breaks:

First, metallurgical inquiries made by the fracture of a definite test piece, purposely broken under definite conditions.

Second, investigations on the cause of breaking in service.

Under this double aspect, and taking into consideration the improvements of our knowledge and investigative technique, we must hope that this ancient qualification test, which is shamefully neglected by many students, will be restored to favor.

ALBERT PORTEVIN

Segregation in 0.80 Carbon Steel Ingots

STOCKHOLM, Sweden.—Solidification structure of ingots has been extensively studied in several countries. Swedish metallurgists have done a considerable amount of work on this subject — reference may be made to the investigations of Berglund (1923) and of Gejrot (1927), both published in Jernkontoret's *Annaler*. Hultgren's studies on crystallization and segregation phenomena in 1.10% carbon steel ingots of smaller sizes are probably well known to American metallurgists, as his report is available in the *Journal* of the British Iron & Steel Institute, 1929, No. II, p. 69.

On account of his somewhat unusual method of investigation, the recent work of B. D. Enlund, published in *Vermländska Bergsmannaföreningens Annaler*, 1930, is worth special mention. Enlund has been interested in the electrical conductivity of steel, and has studied for several years the influence of the carbon content of the steel in the hardened and in the annealed state as well as the influence of the other constituents. These studies have led to the invention of a method for controlling the carbon content during the steel-making processes. He has now employed conductivity measurements, in conjunction with ordinary metallographic methods, for studying the heterogeneity in 0.80% carbon steel ingots.

The object of Enlund's investigation was to show how the method of killing the steel influenced the solidification structure and the heterogeneity. The steel studied had an approximate carbon content of 0.80% and was made by the acid open-hearth process. Ferrosilicon and ferromanganese were added in the furnace. Two 12-in. ingots were set aside for the investigation, the only difference between these being that to one of them about 0.1% of aluminum had been added during pouring, while to the other one no extra additions were made to quiet the metal.

For studying the variation in composition, discs 40 mm. thick were obtained, and across the center of each of these a bar 40 mm. wide was cut; it was then rolled into a 5.5-mm. rod. In this manner the length of the original test bar was multiplied 60 times. The conductivity of successive lengths of these rods was then measured, and in this way the variation of the carbon content across sections of the ingots was determined in a comparatively short time.

Among the results so obtained, checked by microscopic studies, it was found that the addition of 0.1% aluminum had a marked influence on the solidification structure and the degree of segregation; it prevented the formation of a sedimentation cone and in that way greatly reduced the degree of what Hultgren calls "segregation on a large scale."

On the other hand, in the test ingot to which no aluminum was added, there was found a pronounced negative segregation at the bottom and a positive segregation at the top (probably

Foreign Letters

due to evolution of gas) which caused a motion in the melt during solidification. The aluminum-treated ingot showed evidence of a much calmer freezing period.

EINAR ÖHMAN

Strength of Deformed and Aged Steel

TURIN, Italy. — In a previous letter it was stated that one of the best results obtained at the Aosta steel works from very pure raw materials was steels highly resistant to "aging." Since this phenomenon is now attracting a great deal of attention, especially from automobile makers, it will perhaps be interesting to relate a few tests on one typical example.

The data to be given were abstracted from an official report of extensive experiments carried on in the testing materials laboratory of the Royal Engineering School at Turin. Of a number of steels investigated I will select a mild carbon steel, manufactured in the Aosta steel works by the duplex process, under the conditions described in my letter printed in January METAL PROGRESS. (Pig iron is blown in a converter and the steel transferred to an electric furnace where special care is given to the refining and finishing operations.)

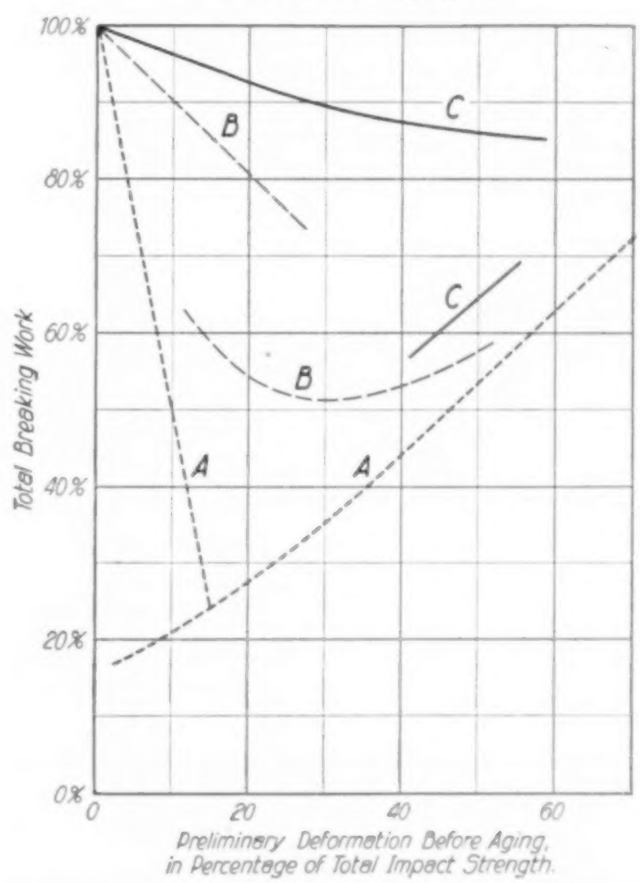
The method of R. Zoja was adopted for the aging tests. According to this method the test pieces are submitted to preliminary deformations, produced by impacts of a gradually increasing intensity but of such an amount that the steel is able to resist them without fracture. The aging time is artifically shortened by reheating at 500° F. At this temperature it is known that the change in physical properties after about four hours corresponds to the total achieved at ordinary temperature in a practically indefinite time. The artificially aged test pieces were then submitted to the ordinary impact test. The total breaking work is taken to be the sum of the work spent for producing the preliminary deformation and the work required for the subsequent fracture of the piece which is being tested.

In one group of experiments the following results were obtained:

	Bars	Total Breaking Work in Kg-M. Maximum	Minimum	Average
As rolled	8	21.88	19.96	20.76
4 kg-m. and aged	8	20.46	18.73	19.67
5 kg-m. and aged	8	20.64	17.64	18.80
7 kg-m. and aged	8	20.73	16.36	17.86
10 kg-m. and aged	3	18.40	17.64	17.97
	5	12.07	11.99	12.05
12 kg-m. and aged	2	17.73	17.61	17.67
	6	15.18	13.10	13.99

The above figures show that this steel maintains its total impact strength quite well as long as the preliminary deformation is of moderate amount. It also exhibits the well-known phenomenon of dispersion of the values for impact resistance, accompanied by the appearance of a new low figure for the total breaking work.

Loss of Impact Strength of Three Steels After Minor Deformation and Accelerated Aging



Foreign Letters

This, however, takes place only when the piece is aged after very great preliminary deformation — in fact, only when the work absorbed by the first deformation has reached about 50% of the work necessary for breaking the original non-aged test piece.

For the sake of comparison, curves are given which plot data taken from the above-described test with the corresponding figures obtained from two commercial structural steels obtained elsewhere.

Steel *A* is a regular open-hearth carbon mild steel; *B* is a 1% silicon structural steel; *C* is the Aosta duplex steel of mild grade. The results shown for steels *A* and *B* correspond with the average figures obtained for normal commercial steels, whereas the curve for the Aosta steel shows a really exceptional resistance to the phenomenon of aging, as defined by Zoja's method of test.

In the accompanying diagram the total work required to break the specimen is shown as ordinates figured as a percentage of the impact strength of the original non-aged test pieces, while the abscissas correspond to the work spent for producing the preliminary deformations as a percentage of the total required for fracture.

The diagram shows conspicuously that the Aosta non-aging steel made by duplexing very pure iron is far less damaged by cold work (has a smaller loss by aging) than steels manufactured under normal conditions from ordinary raw materials.

Federico Giolitti

Metals in R-101 Beyond Criticism

Sheffield, England. — R-101, the largest airship in the world, crashed in the North of France in the early morning of October 5, 1930, at the beginning of an intended flight to India. Fire broke out immediately, and of the 54 persons on board only six escaped with their lives. As the men with the greatest knowledge of airship design and working perished in the disaster, the task of investigating the causes was a difficult one. An eminent lawyer, Sir John Simon, was appointed to hold the inquiry, with two technical assessors, and their report has now been issued by H. M. Stationery Office.

After hearing as witnesses the survivors and eye-witnesses of the disaster as well as experts, a definite conclusion has been arrived at, and the incidents of the disaster have been established beyond reasonable doubt. The changes in construction which were made necessary by the demand for greater lifting power had brought the bags containing hydrogen so close to the metal framework and wires that rubbing occurred, and small holes were made in the bags, leading to loss of gas, especially in the forward portion. The airship thus sank low, and when a dive occurred, the nose struck the ground, and in some way the gas was ignited.

From the metallurgical point of view, the most interesting conclusion in the report is that there was no failure to be attributed either to the engineering design or to the metal construction. The crumpling when the airship struck the ground was only slight, and the damage shown in photographs of the wreck was caused by the subsequent fire.

R-101 differed from similar vessels in its mode of construction. It was built up of sections which were constructed in workshops and then assembled at the place of erection. The members were manufactured to jigs at Norwich and assembled at Cardington. As was pointed out in Metal Progress immediately after the wreck, the materials used were mainly stainless steel and duralumin, the booms being of stainless steel strip and the ridge girders of stainless steel with duralumin webs. The duralumin was anodically oxidized as a protection against corrosion. Die-cast joints were used between struts and booms, with drop-forged steel shackles for adjusting wires. In the making of the steel members, steel with 0.16 to 0.22% carbon and 12.5 to 14% chromium was employed, the soft annealed strip being drawn and then heat treated. Duralumin was quenched, then drawn.

The most novel feature, apart from the engineering design, which *(Cont. on page 104)*

HOMES OF METAL

WHY is it that more metal is not being used in the construction of homes?

Vigorous publicity by Copper & Brass Research Association has made the home-owners copper-conscious to the extent that more copper eave troughs and down spouts, more bronze window screens, and more brass hot-water piping is being used in newly built houses, but this merely replaces other less durable metals formerly used for the same purpose.

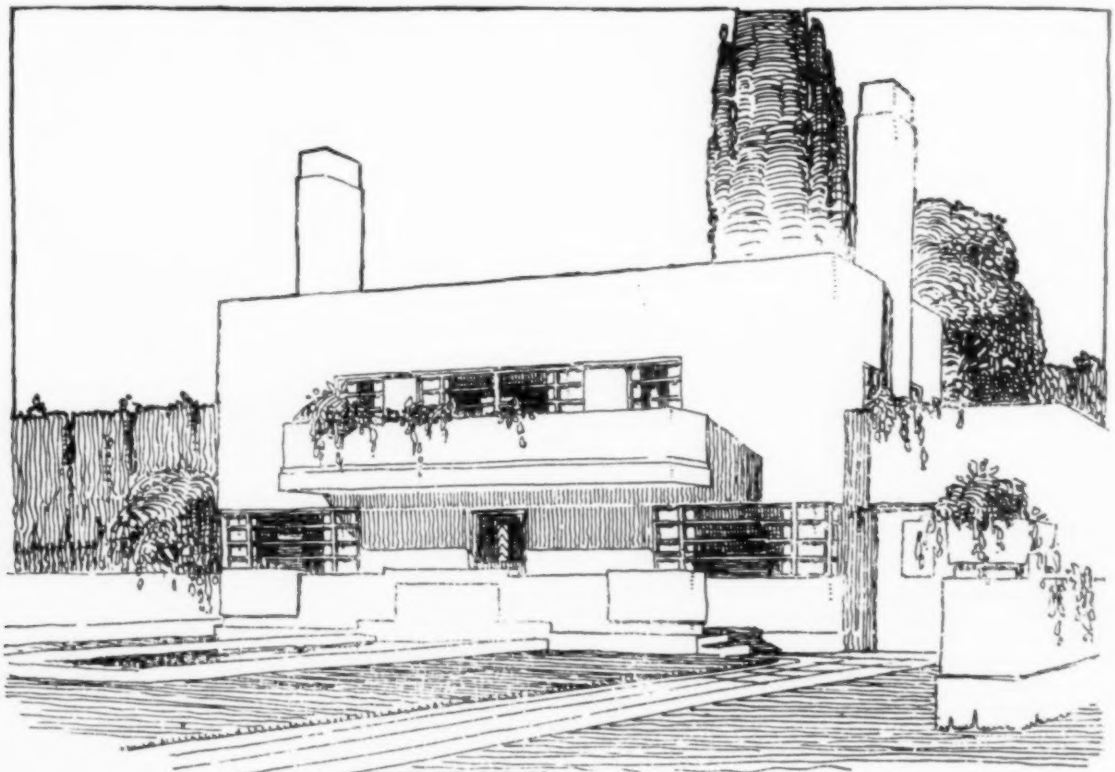
Nevertheless, other new materials have been popularized in a few years: Electric appliances, linoleum, enameled sanitary ware — to mention a few outstanding examples.

Perhaps the reason is that the successful innovations are popular because they offer some conveniences never before available, or, if merely a substitute for something already possessed, they are more attractive or more durable and at a competitive price.

At any rate, metal framing for homes has been available in this country ever since the steel skeleton buildings began to be erected. Architects have been prompt to seize upon steel as an essential building material for their larger structures — indeed, the modern office building or manufacturing plant would be impossible without it. Here the metal offered some conveniences never before available, and is even competitive in price in the smaller constructions. Yet, when metal for framing residences is placed on the market, as it has been for several years, almost no one is willing to accept it. This situation is probably due to the fact that it is merely offered as a substitute for wood or brick, and at a price which is not competitive.

A historical note may be in order. The first metal-framed house was built early in the 19th century. Today, a century or more later, steel frame houses are still rare enough to cause comment. Yet, the serious entry of metal into home building will raise the appallingly low efficiency of house construction, and, when all its collateral advantages are realized, will reduce the tremendously inflated cost of urban housing. It has been estimated that the efficiency per man in the construction trades is 50% less than it was 15 years ago. This contrasts with an increase of 172% in man-efficiency in the automobile industry during the same period! Homes built from standardized, factory-made units will, of course, be cheaper and need by no means result in rows upon rows of box-like structures, all identical.

Engineers, architects, and builders in America will probably be brought to study the use of metal in small homes by two converging movements — (a) the adoption of metal by the "functionalists" abroad, and (b) the greater utilization of metal for exterior walls and interior partitions in large office buildings and apartments.



Typical Double House in the English Garden Village of Silver End, Wessex. Metal used freely in the mass construction of 400 modern houses, selling for $300 per room

In Europe, especially in Germany and France, a new school of architecture is using metal not only as framework but as exterior sheathing, somewhat as does the Chrysler Tower in New York. The continental architects and builders, however, are not limiting themselves to skyscraper construction but include among their works tiny three-room cottages, modest enough in price or size but certainly *not* so in appearance. Herein is an idea well worthy of emulation here — standardize the construction for *small* houses, so that the development builder can put up durable sanitary construction at prices the moderate income can afford.

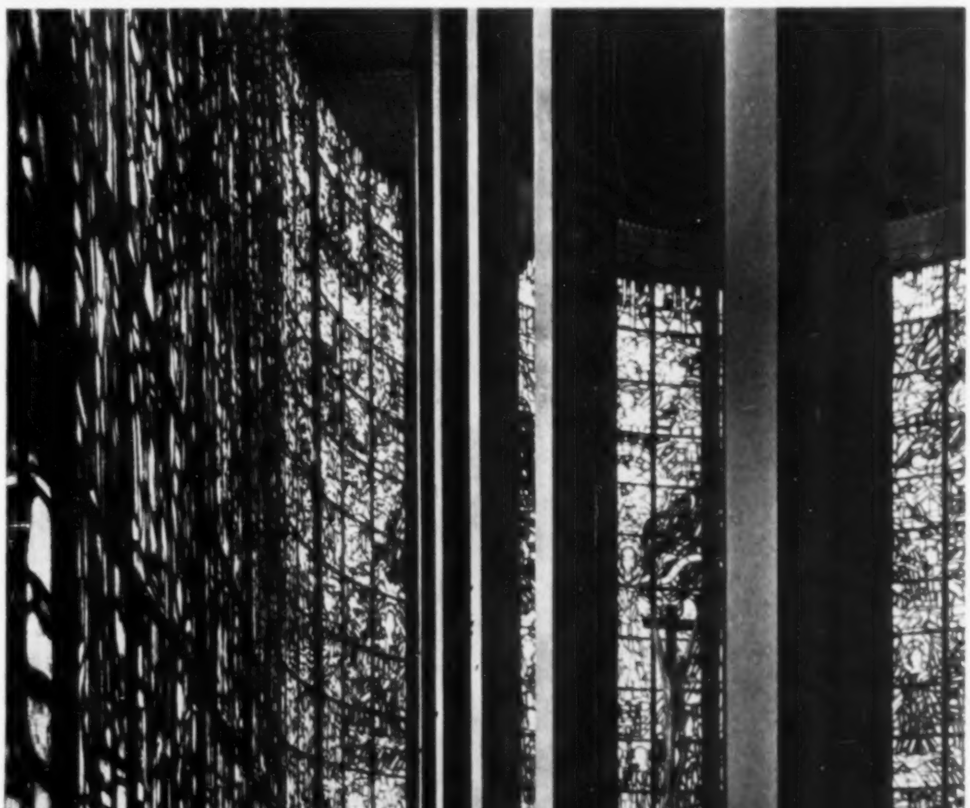
These new thoughts in architecture are expressed by a group called "functionalists" in the patter of the profession. They shun, among other things, all decoration that has no purpose. For this reason they shudder at the sheets of 18-8 on the Chrysler Tower because the shiny sheathing contributes nothing to the strength of the building (albeit the perfectly utilitarian purpose is performed of keeping out the weather). Functionalists (artists, of course) aim always at beautiful proportions and believe that when the structural elements of a building are well proportioned, that building will be beautiful. In this last thought they are in step with the trend of quite a few years; there has been a noticeable change in building and architecture which leads away from highly ornamented rococo architecture, popular a generation or more back.

The metal industry will benefit greatly if this European movement becomes popular with American home builders, and when most homes have structural steel frames, battledeck subflooring, metal shingles on the roof, and either stainless or aluminum sheets on the outside walls. Many continental homes are now built that way; our own Southwest is hospitable to the idea because the inhabitants there have been long accustomed to Spanish and Mexican types of building construction. An adobe house is

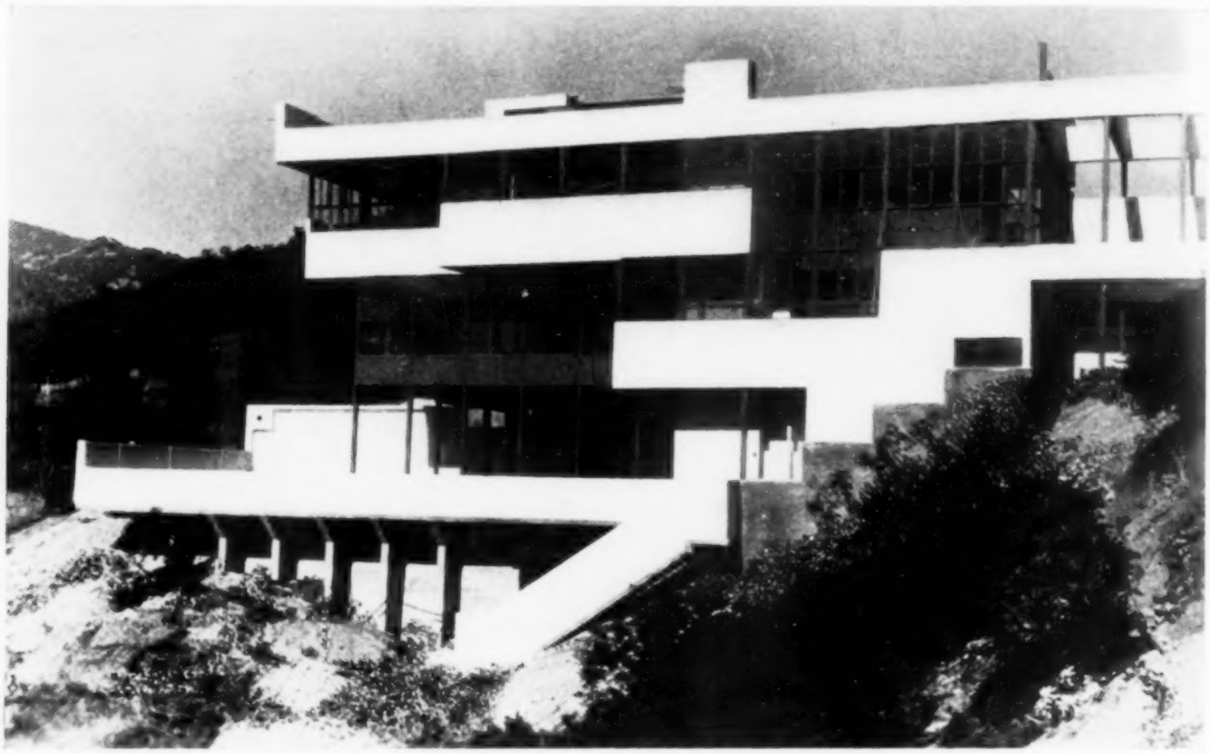
functionalistic, par excellance! At any rate, the logic, utility, and neatness of the creations of forward-thinking architects will eventually appeal to machine-minded Americans.

Metal construction is 15 times as strong as wood, and this feature allows much latitude in design. It is entirely possible, for instance, to build a house with windows extending to the very corner, or to within an inch or two of the doorway. Or instead of thick inside walls of frame or masonry necessary to support the walls, floors, and ceilings, each story can be built as a single room free of obstructions and then subdivided by movable partitions. No difficulty is experienced with long floor spans from wall to wall when steel I-beams replace the 2-in. wood joists.

Flexibility of design is the keynote throughout. Window locations are not influenced by inherent weaknesses in the framework. The feature of movable interior partitions allows the house to be adapted to the changing needs of a growing family, or of a succession of renters. An office building owner who imagines that all his tenants need a 12x15 office and makes no provision for interior rearrangements speedily



Interior View of Best Representative of European All Metal-and-Glass Public Building. Stahlkirche at Essen, Germany, uses bare I-beams for interior columns, thin sheet for opaque wall and roof and even pews. Dr. Otto Bartning, architect. (Courtesy of "Metalcraft")



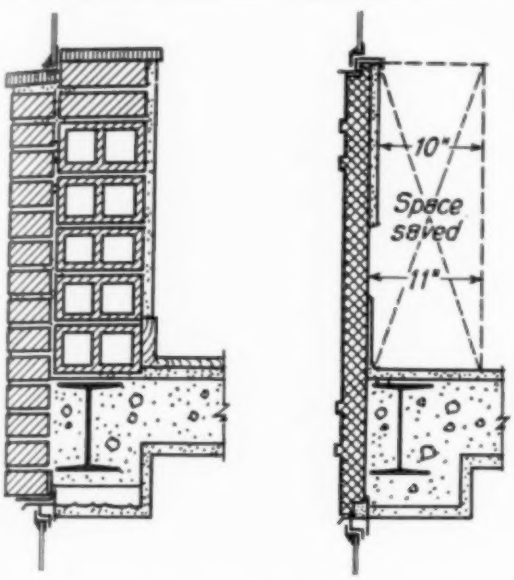
House of Metal Frame and Concrete Slabs in the Modern Manner, Designed by R. J. Neutra. Liberal use of glass is in keeping with Southern California climate

finds that his investment is not making the money it should. Furthermore, low partitions (mere screens) are great for ventilation of cool breezes in hot climates.

Construction of a metal house presents the same difficulty that selling the idea to the owner presents — it is a new thing and most people are very conservative. Furthermore, all kinds of opposition from unionized trades may be expected. A carpenter is used to sawing up 2x4 studs and hammering them into a building frame, blocking window casings into the openings, and nailing up the siding. He doesn't know how to assemble and bolt up a series of steel angle bars, channels, and I-beams, even when each piece is properly fabricated to go into a certain job. Furthermore, he doesn't want to learn! Nor does the contractor want to take the risk of employing a steel erector or a welder to do this work, unless he can charge about 100% for contingencies, and that boosts the price up to where the prospective owner revolts. Lastly, as ought to be obvious, the use of steel studding is not economical unless the whole house is designed to effect the economies which are permitted.

Hence a metal house needs the association of an intelligent architect, an enterprising contractor, and an owner something of a modernist. Any one of these three is rare enough, and the difficulty of getting all three of them together at the same time and place represents the real reason why so few metal houses have been built in America.

As a matter of fact, construction of a metal house presents no difficulties; it has, indeed, certain cost saving features. All the elements are standard. Angles, channels, I-beams, bars, flooring, and hardware — all are widely sold for various purposes, and the unit price is at pre-War levels. Fabrication is either by welding, riveting, or bolting; much of it can be done in a shop. Final assembly in the field is equally simple. The large house pictured above was assembled in six days; its exterior finish consists of unit sections of sheet metal, not thousands of



Economy of Metal Wall Construction Contrasted With Inefficiency of Masonry. Masonry curtain wall is 13 in. thick and weighs 90 lb. per sq.ft. Metal spandrel plastered inside is 3 in. thick and weighs 17 lb. per sq.ft. If a rustless metal such as copper, aluminum, or stainless steel sheet is used with 2 in. of insulation, the thickness is 2 in. and weight 8 lb.

little bricks to lay in place, one by one, by the same methods used when the Tower of Babel was built, but by workmen at $2.50 an hour. Spot welding the sheets to the frame by portable cramps is the most common practice.

Strength of a steel structure permits the architect to reduce greatly the thickness of walls and floors. This puts additional responsibility upon the insulating materials. A typical cross-section of a wall of one of these metal houses shows a thin sheet of polished aluminum or stainless steel on the outside. Then come two ½-in. sheets of gypsum rock board separated by rock wool, or an equivalent slab of one of the prepared insulating materials now on the market. Expanded metal lath, welded to the steel frame holds the plaster and interior finish. The whole wall would be less than 4 in. thick, as compared with 12 or 13 in. necessary for brick walls or a brick facing over a wooden frame.

Metal supports and framing are stout and rigid enough so that windows can be placed wherever desired, and of any size to suit architect and owner. In warm, sunny California we find a trend toward wide expanses of glass. Even in the north, glazed "sun parlors" have not yet outlived their usefulness. The cheapening of quartz glass or other varieties which pass the ultra-violet rays will doubtless see a recrudescence of this detail of house construction.

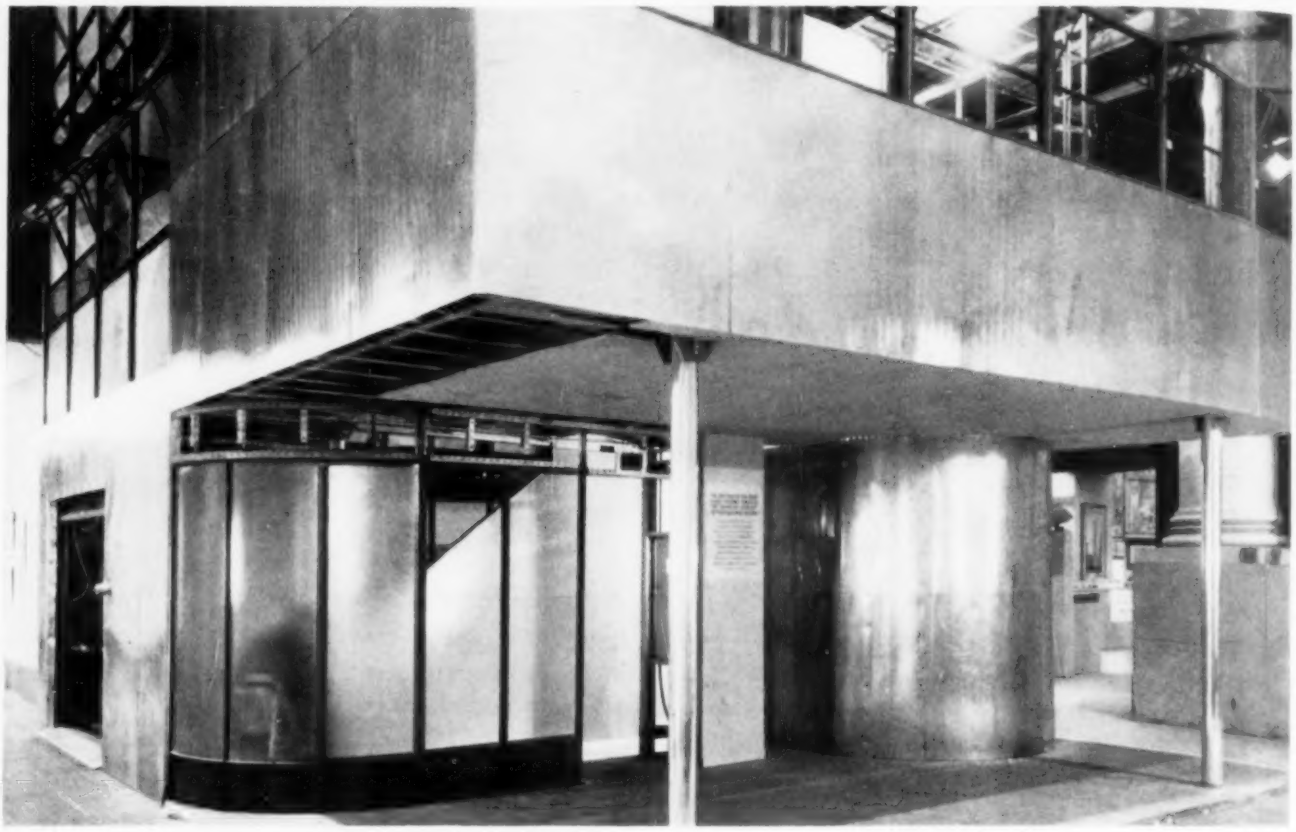
Passing now from the principles of modern house building as adopted abroad, consider the approach which American architects are making from the angle of large building construction, a feature of American architecture.

So much has been printed about the recent use of metal for exterior trim that nearly every one has seen pictures of the vertical stripings made by covering the pilasters of high buildings with stainless steel. Fewer have noted an increasing use of metal for the spandrels — the wall portions between pilasters, extending from a window top to the window sill on the floor above. Ordinarily these have been backed by brick, but the accompanying diagram indicates how the metal spandrel, being self-supporting, really needs only some insulation and interior finish to save 10 in. of wall space, and 80% of the weight. With office buildings renting for $3 to $5 per sq.ft. a year, this item of thickness of walls (and of partitions) has sufficient economic importance to deserve careful consideration from architects and building owners.

Insulation Advantages Are Possible

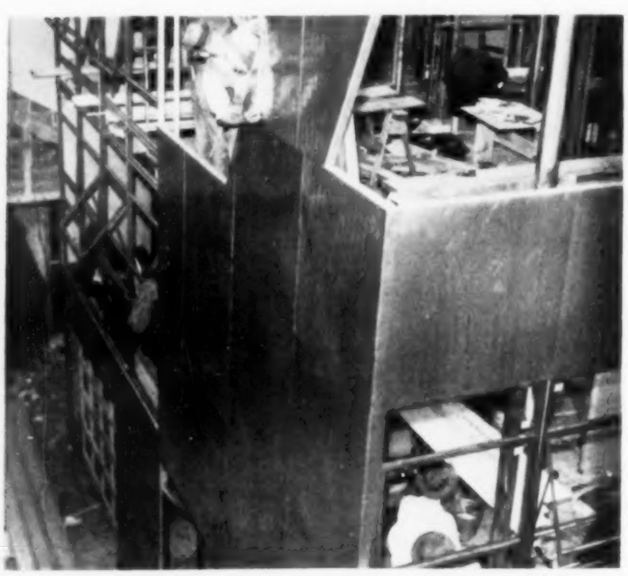
Other desirable qualities may be built into such a construction. Approximately 8 hr. is required to bring the interior surface of a 13-in. brick wall to room temperature; a double metal wall with 2 in. insulation between faces reaches temperature in 10 min. and radiates only half as much. Bureau of Standards studies show that double-ply metal walls with insulation are more effective sound deadeners than average partitions, and perforated metal backed by sound-absorptive material will absorb 20 times as much sound as smooth plaster.

Such advantages as these will be impressed upon the architects who become designers of houses for development corporations. Apparently, only in this way can mass production of the various units be started, and bring to the average home the benefits of metal construction.



Front Porch of "Aluminaire," the Metal House Exhibited by New York Architectural League. At left rear is garage door; toward front is glass-enclosed entrance hall; at right is circular wall enclosing heating plant. Above porch roof is bedroom, kitchen, and bath. Above garage is a combined living and dining room two stories high. Third floor is library and roof garden

Metal House Under Construction. Aluminum sheet over steel frame.. The sheet is ribbed with tiny sharp ridges to reduce the glare and to avoid expansion cracks. Designed by A. L. Kocher and Albert Frey



It is a movement which should be hastened, for the great majority of American houses are in reality not the well-designed and well-built houses of Colonial or English tradition, but flimsily built boxes built without benefit of expert advice.

So far the advances in steel construction have been made by the engineer, rather than the architect. Lewis Mumford, a prominent American architect, believes that the latter may have great opportunities in the new developments. He recently said:

"If the decision against conspicuous waste cuts the designer off from the single wealthy patron, let him be consoled by this: The community as a whole is a much wealthier patron, and once it begins to be well-housed and furnished — even a "prosperous" country like the United States is far from such a general goal — once it begins to demand modern and well-designed houses, as it now demands its 1930 model car, there will be more work for the artist in the factory than he has dared to dream of for many a century, as he waited in the anterooms of the well-to-do."

Mechanical Pickling

because of size or shape or a great variety of sizes and shapes. Tank pickling, supervised by intelligent workmen, is then necessary.

When production can be taken care of in baskets of not over one ton capacity, an electric or air hoist may be used to raise and lower loads and transfer them from tank to tank. Although an air hoist is less expensive, it is not generally adaptable where a track is used over a long series of tanks, owing to the difficulty of maintaining the necessary hose connections. If an electric hoist with a specially impregnated winding is installed, speed of handling with low maintenance cost is obtained.

Drop sections in overhead trolley tracks, such as shown on page 67, are suitable for dipping, cleaning, painting, or plating of either a few large or numerous small articles. Such an expedient saves the expense of a hoist on each carrier, since only one hoist is requred for each drop section, which may handle two or more carriers, depending upon the size of the tank beneath. Loaded carriers can be run onto the drop section, submerged in the dipping tank, then raised, run to another drop section where the process can be repeated or the load removed.

Safety devices should be installed to prevent a carrier from running off the end of the permanent tramway, or from running off the rail when the drop section is in any position except joined up with the overhead rail.

Drop sections are best hoisted by a base-mounted electric hoist. These can be located directly above the sections or in some convenient place at either side, as would be especially desirable when heavy acid fumes are evolved from the tanks beneath. When the hoist is placed in a remote position, cables running over appropriate sheaves are necessary to secure a direct vertical lift at the tank.

Push button control for hoisting is preferred for all drop sections, although other methods of control have been found to be suitable. Shock absorbers should be provided to relieve any impact which might occur.

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Ultimate Tensile Strength	92500
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284 heats in six months
from laboratory furnace

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Die Casting

(Continued from page 78). For size and complexity it compares favorably with the more difficult white metal die castings of today. The die in which it was produced comprises all of the major elements of a die-casting die: A core plate, an ejector plate, and side cores, all operated automatically.

Another view is shown of a second gate of brass castings. Whereas the first one is "center" gated, this one is "end" gated. Both were produced on the same machine, the change in gating requiring only a slight adjustment of the machine. On this gate is one casting with a wall thickness of $\frac{1}{16}$ in. at some places, as well as another casting having a wall thickness of about $\frac{3}{8}$ in. Two side cores are also required for this group, one of them being $2\frac{1}{2}$ in. long and $\frac{1}{4}$ in. diameter. Those familiar with die casting practice in zinc and aluminum base alloys will recognize in this gate a subject of abnormal difficulty from the standpoint of casting in either zinc or aluminum base alloys by present methods.

Brass castings made by this process by the Nikko Copper works of Japan have surfaces, as removed from the die, smooth and perfect enough to pass rigid inspection. Small cores intersecting at right angles, steel inserts, thick and thin sections, and long thin shafts—none of these in the process cause any difficulties.

This paper has not been intended for a detailed study of the work that has already been done in placing the pressure casting art on a sound and dependable basis. Such a report would be too voluminous for the present purpose and somewhat premature in view of pending patents. The writer believes, however, that enough data have been presented to demonstate the fact that the die casting of the future need not be considered merely as a cheaper product, but rather as a product of higher quality. Furthermore, it is quite evident that the pressure casting process of the future will not be limited to a few special alloys, but the process will be available for the casting of almost any alloy that will meet the specifications of the user.